LIQUID STEEL

ITS MANUFACTURE AND COST

DAVID CARNEGIE

ASSISTED BY

SYDNEY C. GLADWYN

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DAVID CARNEGIE

F.R.S.E., M.INST.C.E., M.I.MECH.E., M.I.S.INST.

STEEL WORKS CONSULTANT AND ENGINEER, LONDON

FORMERLY IN CHARGE OF SHELL FACTORY, ORDNANCE FACTORIES, WOOLWICH ARSENAL; WORKS MANAGER OF THE HADFIELD STEEL FOUNDRY CO., LTD., SHEFFIELD; AND CONSULTING ENGINEER (AND GENERAL MANAGER, STEEL FOUNDRY) TO MESSRS. SAMUEL OSBORN AND CO., LTD., SHEFFIELD

ASSISTED BY

SIDNEY C. GLADWYN

WH.EX., A.M.INST.C.E. (BAYLISS PRIZEMAN)

CONSULTING ENGINEER, LONDON

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PREFACE

In preparing this treatise I have attempted, with the help of Mr. Gladwyn, to set forth and compare the various items of cost in the different processes of steel manufacture of any commercial importance. Its perusal, I hope, will stimulate a closer study of this most essential side of steel manufacture.

It is generally accepted that where metallurgical and engineering research does not aim at improving the quality and reducing the cost of steel products, its business interest to the manufacturer is of little moment.

Several standard works on the metallurgy of steel, to which reference has been made in the following pages, deal in some measure with the cost of steel manufacture, but so far as I am aware no previous attempt has been made to compare systematically the costs of all the steel-making processes, having in view their metallurgical and engineering significance. It is my belief, as the outcome of several years' experience in the construction and management of modern steel works, that the facts given herein will be welcomed by steel manufacturers, managers, engineers, metallurgists, chemists, draughtsmen, and all others who are interested in the efficient equipment and control of steel works.

Information and data of practical use to steel makers generally are given, including—

1. The analyses and costs of iron ores, pig irons, refractory materials, fluxes, ferro-alloys and fuels, all of which are principally arranged in tabular form for easy reference.

2. The composition of charges for different classes of steel, with particulars of the finishing additions required.

3. Details of the construction, arrangement, and cost of furnaces and plant.

4. Methods of assembling steel works' costs and details concerning the value of labour and the costs of living in various industrial countries.

It is, however, particularly desired to emphasise the importance of the study of costs in steel manufacture to students of metallurgy. A systematic treatment of the subject, not only as applied to iron and steel, but to all metals worked commercially, might be introduced as part of the metallurgical course at universities and other educational institutions. The subject has already received some attention in the high schools of Germany and in the U.S.A., and I was pleased to learn from Dr. Hamerschlog, while on a recent visit to the Carnegie Technical Institute, Pittsburg, U.S.A., that the importance of teaching students the money value of materials in the raw and manufactured states, together with their physical and chemical values, was being recognised.

When consideration of the cost of producing iron ores, pig iron, refractory materials, fluxes, ferro-alloys, steels, etc., is carried on simultaneously with the study of the analyses, qualities, and uses of these materials; when the cost of furnaces and their maintenance are noted with the facts of their design and operation; and when questions relating to the value, classification, hours, and payment of labour in different steel-making countries are taught in conjunction with the methods of manufacture employed, the result is bound to be of great practical value to the student when he passes from the lecture room to the laboratory and the works.

In the preparation of the present volume valuable help has been obtained from the works of Arnold, Bell, Campbell, Harbord, Howe, Stead, Wedding and other gentlemen, to whom reference is made in the text.

I desire, with Mr. Gladwyn, to thank the Council of the Iron and Steel Institute, the Editors of "The Iron and Coal Trades Review," "The Iron Age," "The Foundry," "The Foundry Trade Journal," "Stahl und Eisen," and others for the use of illustrations, etc.; Dr. Cooper, President of the Iron and Steel Institute, Mr. Benjamin Talbot, Mr. Twynam, Dr. O. Petersen, Mr. E. Widekind, and many others who have furnished details regarding British, American, and German steel works practice.

I wish to record my indebtedness to Sir Robert A. Hadfield, F.R.S., for the incentive he gave me, while I was engaged at his works in Sheffield, to prosecute the study of steel; and to Sir H. Frederick Donaldson, K.C.B., President of the Institution of Mechanical Engineers, for inspiring the study of the economic value of labour, its classification and standardisation, when serving under him in Woolwich Arsenal.

DAVID CARNEGIE.

LONDON,
April, 1913.

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CHAPTER I

INTRODUCTION

THE uses of steel are so numerous that the demand for this material for railroads, steamships, bridges, and structural work of all kinds has increased with amazing rapidity during recent years. Steel is gradually replacing cast iron in all branches of engineering. In almost every scheme with which the engineer has to deal, rolled, cast or forged steel, in one form or another, is required. The large increase in the demand has called for the development of old processes and the establishment of new ones, in which iron ores, formerly considered too impure for use in steel manufacture, are now being utilised with satisfactory results. This has led to an increase in the number of works producing steel in Britain, but more particularly on the continents of Europe and America, and in other countries where it has been found practicable and commercially economical to use local ores.

The following particulars[1] give some idea of the development of steel manufacture during the years mentioned :—

OUTPUT OF INGOTS IN THE WORLD, 1880–1910.

	Year—1880	1890	1900	1910
United States America . . .	1,175,119	4,202,103	10,082,905	25,917,281
Germany	760,000	2,161,817	6,510,215	13,315,437
United Kingdom	1,295,382	3,579,043	4,901,058	6,010,684
France	384,626	688,991	1,565,164	3,361,517
Russia	307,305	372,625	2,186,399	3,239,616
Austria-Hungary	134,218	499,600	1,145,654	2,136,203
Belgium	132,052	236,226	654,827	1,892,160
Canada	—	—	23,954	803,600
Italy	—	157,899	115,887	635,000
Sweden	30,013	160,026	298,483	468,600
Spain	—	—	150,734	219,500
Other countries	—	—	400,000	315,000
Total . . .	4,218,715	12,058,330	28,035,280	58,314,598

Competition.—The establishment of steel works in different countries has led to serious rivalry and competition between the manufacturing nations.

[1] Presidential Address, "Journal Iron and Steel Institute," 1912, I, pp. 48 and 49.

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Where sources of ores have been found and steel manufactured in countries where all its requirements for steel had been previously supplied from the older established steel-making centres of industry, the supply from the latter has necessarily decreased, or the prices have been reduced to meet the competition arising from the new source of supply. In any case, as a result of the increased supply, selling prices have been reduced to maintain trade, necessitating considerable economies in labour, raw materials, fuel, power, etc., in all the processes of manufacture.

Modern Plant.—In some of the old-established steel works in England, a complete reorganisation has been carried out, and modern plant introduced, in order to meet German and Belgium competition in our own markets. Much, of course, has been written about the imposition of tariffs, with the object of checking the surplus supplies of steel from the Continent at prices below which we cannot manufacture with a profit at home, but it is somewhat doubtful whether tariffs would prove to be entirely effective. From our experience of Continental and American steel works practice, we are convinced that works and plant reform will be largely effective in meeting all foreign competition.

Cost of Steel Making.—Modern plant is not the only requirement in producing steel cheaply; the cost of labour, raw materials, fuel, power, freights, etc., vary considerably in the different countries, and influence the final cost of steel. The natural resources, also, of one country differ from those of others, giving certain advantages over the less fortunate countries. Considering, however, the costs as a whole, it is generally found that where the processes employed are the same, the final cost of production varies only slightly in different countries. What does materially influence the cost of steel produced is the employment of that process which is most suited for the classes of raw material and fuel available for the manufacture of the product required. For instance, the use of the immense native phosphoric ore deposits of Germany was only made possible by the introduction of the Basic process.

With the object of comparing the values of the various known processes, we have set forth briefly the merits of each in the succeeding chapters, together with the details of costs of plant, working costs of manufacture, and methods of assembling costs.

The following considerations have been kept in view in comparing similar processes:—

1. All items of cost of manufacture are included up to that stage where the liquid steel is ready for use.
2. The steels produced in similar processes conform to the same standard of tests, unless otherwise stated.
3. The same outputs are taken during like periods.
4. The cost of raw materials, fuel, power, labour, etc., for like processes are taken at the same market values.

There are, of course, other items of cost which are included in the complete summary of costs, some of which vary according to the plant used, local conditions, and the methods of management adopted.

Processes of Manufacture.—While many types of furnaces are used in steel manufacture, the processes are limited to the following:—

1. Crucible.
2. Bessemer.
3. Open Hearth.
4. Electric.

The scope and usefulness of the furnaces in each process are limited in some measure by the weight, quality, and rate of output of the product.

1. Crucible Process.—Crucible furnaces are used as a rule for the manufacture

of all classes of tool steel, and for light castings of higher quality than are obtained from the other processes, except perhaps in the electric furnace, where the quality of the output can be regulated according to the purity of the materials melted. The output is necessarily comparatively small, as the average capacity of crucibles is from 60 to 100 lbs. each, and the castings made from the steel vary from a few ounces in weight to 50 or 100 lbs. Usually the ingots of tool steel are of such weight as is given by the contents of each crucible. There are instances, however, where this process is employed for making large ingots of steel for ordnance work. A few years ago we witnessed, at the works of Messrs. Krupp, of Essen, the casting of an 80-ton ingot from steel melted in crucibles. Several hundreds of crucibles of steel were melted at the same time, the contents of which were poured in quick succession into the ingot mould. This is, perhaps, an exceptional instance of the use of the crucible process for such a heavy class of work. Nevertheless, it is a daily practice at the works of the Crucible Steel Co. of America, to make high-grade steel ingots for projectiles and other work, each weighing about 1500 lbs., from crucible furnaces melting steel in 100-lb. crucibles.

These instances show that although the scope of the process is limited, it is used in some works for the manufacture of steel ordinarily produced in furnaces whose capacities admit of handling larger quantities more easily.

Different forms of furnaces are illustrated, in which are used : various fuels, such as coal, coke, oil, coal gas and natural gas, with natural and forced draughts; crucibles of different shapes and qualities; and various linings. In the numerous designs, however, there has been no important departure from the principle underlying the process originally carried out by Benjamin Huntsman at Sheffield, which is essentially one of melting, although slight chemical changes take place in the materials during the operation.

In Part I, where this process is described, the costs given are taken from furnaces actually at work, and are fairly representative of modern practice at home and abroad.

2. Bessemer Process.—In Part II we discuss the merits of the Bessemer Process. This process stands out quite distinctly from the Crucible, Open-hearth and Electric Processes. The great importance of the revolution Bessemer made in the manufacture of steel can be appreciated when a comparison is made between the outputs and costs of steel produced before its introduction and those recorded for the different steel-making countries now. The principle of the process is well known, but is none the less wonderful as an important and far-reaching discovery.

Many types and sizes of converters are used, having capacities ranging from a few cwts. to several tons.

The side-blown type of converter, known by different names, is used principally for charges not exceeding 3 tons of steel, and in this size it is found to be, in most countries, very suitable and economical for steel foundry use. Sometimes one, two, or more converters are arranged side by side in one foundry, and by the use of them together, castings well over 10 tons in weight can be produced.

Converters of the bottom-blown type, having small capacities from 2 tons upwards, are also used in steel foundries, but they do not appear to be so popular as the side-blown converters.

In large steel works producing steel ingots for rails, structural materials, etc., the side-blown converters are not used. Bottom-blown converters with capacities up to 35 tons,[1] or else some form of open-hearth furnace, find most favour. The various types of converters and their uses, together with the costs of steel

[1] "Journal Iron and Steel Institute," 1912, I, p. 44.

manufactured in them, are described and compared with the other processes doing the same kind of work. Several typical arrangements of works in which Bessemer steel plants are used, are described and illustrated.

3. Open-hearth Process.—We include in Part III, under this heading, all forms of open-hearth furnaces, also gas-producers, mixers, furnace-charging machines, and other appliances used in connection with the furnaces. It will be observed that many modifications have been made in the design of open-hearth furnaces since first introduced by Sir William Siemens and his brother Frederick. There are fixed and movable furnaces of numerous types and sizes used in different works. Their use in steel foundries is not, perhaps, so common in some countries as that of the side-blown Bessemer plants, although open-hearth furnaces with capacities varying from a few cwts. up to 25 tons are employed with satisfactory results.

Open-hearth furnaces of the fixed type are not usually made above 100 tons in capacity, but tilting furnaces of the Campbell or Wellman type are made for use of steel manufacture by the Talbot process up to 250 tons capacity. The various types of furnaces are described, and their uses discussed and compared with each other and with Bessemer furnaces. Details of the costs of producing steel from the different types of furnaces are given. The values of acid and basic linings are also considered.

The duplex processes, in which the Bessemer converter and the open-hearth furnace are used jointly, and also in which open-hearth furnaces are used together with electric furnaces, are also described.

The arrangements of O.H. furnaces and the accompanying equipment of steelworks in relation to the blast furnaces and mixers, from which the supply of hot metal is obtained, together with details of casting shops, are described and illustrated.

4. Electric Process.—In Part IV the various types of furnaces described show what has been done and what is being done in steel making by the use of electricity. Many experimentalists are carrying out researches with the object of producing steel more economically and of better quality with the electric furnace than by any other steel process. We do not see why the use of this furnace should not be extended, but it is a fact that even with cheap power in the U.S.A. and Canada, other types of furnaces are preferred. Many important firms have installed electric furnaces and are obtaining satisfactory results from them. From the details of costs we have given it will be seen that the furnace has an important place in the manufacture of steel such as is now being produced in the crucible process.

The furnaces are classed under the following divisions:—

1. Arc Furnaces.
2. Induction Furnaces.
3. Arc Resistance Furnaces.
4. Combined Arc and Resistance Furnaces.
5. Resistance Furnaces.

These various types are described and compared, and the working costs of those actually in operation, together with the costs of steel produced, are given.

Raw Materials.—The iron ores, fluxes, fuels and manufactured raw materials for use in steel making to which we have referred, are not by any means dealt with in an exhaustive manner, our principal object being to bring out the commercial values of the materials used in the processes described rather than their chemical and physical values, which are found in standard works on Metallurgy. As, however, the chemical and physical values have an important bearing on the cost of the materials, the analyses and composition of the charges have, as a rule, been given, as well as the costs.

The analyses of the materials and compositions of the charges should be regarded as typical only. Numerous variations in these respects are made according to the kind of process of steel manufacture employed and the cheapest and most suitable materials available. The prices we have given are subject to variation, but can be taken as comparative and average standard prices.

Labour.—As the cost of labour is an important item in steel manufacture, we have attempted to compare the cost of labour and living in the leading steel manufacturing countries of the world. The statistics given have been obtained during personal visits to the countries in question, and from other reliable sources of information to which references are made in the text.

CHAPTER II

MATERIALS USED IN STEEL MANUFACTURE

Most of the materials described in the following sections are employed, in some form, in all the processes of steel manufacture. The principal sources and outstanding characteristics of the raw and manufactured materials used are briefly described in the following sections, which include :—

1. Ores.
2. Pig Iron.
3. Refractory Materials.
4. Fluxes.
5. Fuels.
6. Ferro-Alloys.

In Section V on Fuels, reference is made to methods of generating electric power and also to its use and commercial value in steel manufacture.

SECTION I

IRON ORES

Few processes of steel manufacture convert the ores direct into steel, the usual stages being—

1. From ore to pig iron.
2. From pig iron to bars (by puddling and rolling), for use principally in the crucible process.
3. From pig iron to steel, either by the Bessemer or one of the open-hearth furnace processes.
4. From pig iron to steel by partial conversion in the Bessemer converter and finishing in the open-hearth or electric furnace.
5. From pig iron to steel by partial conversion in the open-hearth furnace and finishing in the electric furnace.

In the foregoing methods, steel scrap previously made from pig iron is used again in various proportions in the different furnaces for remelting. Also certain proportions of ores are used in the open-hearth processes for the oxidation of impurities.

Deposits of Iron Ore.—The deposits of ores are very numerous and vary considerably in character and extent. The increasing demands for iron and steel have encouraged explorations, the records of which show that the iron ore resources of the world are almost inexhaustible. We give below the following summary of the world's iron ore reserves as given in one of the papers[1] presented at the Eleventh Annual International Geological Congress, Stockholm,

[1] "Iron Ore Resources of the World." Stockholm, 1910.

1910. The figures in the column headed "Potential Reserves" include low-grade deposits, etc. The columns headed "Iron" give the amounts of metallic iron in the ores.

TABLE I

Summary of the World's Iron Ore Reserves (in million metric tons)

Continent.	Actual Reserves.		Potential Reserves.	
	Ore.	Iron.	Ore.	Iron.
Europe	12,032	4,733	41,029	12,029
America	9,855	5,154	81,822	40,731
Australia	136	74	69	37
Asia	260	156	457	283
Africa	125	75	Much	Much

Analyses of Iron Ores.—Oxide of iron forms the chief constituent of iron ores which are of any commercial value for iron or steel manufacture. Iron ores are always associated with other minerals when found in the earth. The yield of iron from ores differs considerably. In the following table, in which are given analyses of the principal iron ores, the percentages of metallic iron obtained from the ores are also given. It will be observed that the yield of iron varies from 25·8 per cent. to 66·6 per cent. in the ores tabulated. The ores richest in iron are the hematites and magnetites, but even with these there are poor qualities, as will be noticed in comparing the analyses closely.

The purity of an iron ore depends upon its freedom from sulphur and phosphorus. The presence of either of these elements in excess of 0·02 per cent. to 0·03 per cent., is considered injurious in crucible steels used for high-speed tools, hence the use of pure ores such as are given in the table under item No. 4, which is the analysis of the much-used ore from the mines of Dannemora in Sweden, used chiefly for the highest qualities of tool steel.

The presence of phosphorus and sulphur in higher percentages, *i.e.* from 0·04 per cent. to 0·08 per cent., in steels such as are used for steel castings, structural steelwork, rails, plates, and the like, is not so injurious, and hence the use of iron ores in which more phosphorus and sulphur are found. Recourse is only made to the use of impure ores because of the prohibitive cost and limited supply of the purer ores.

Since the introduction of the basic linings in the various steel furnaces, the removal of phosphorus from the ores has become an accomplished fact, but before that time many ores, although otherwise valuable, could not be used for steel manufacture. The removal of sulphur is not so easily accomplished, and it is only eliminated from the iron in a slight degree in some of the processes. Research is still required for the purpose of finding some simple and economical method of removing the sulphur from the ores and preventing its return to the steel from the fuel used during manufacture.

Cost of Iron Ores.—The commercial value of an iron ore does not depend only upon the yield of metallic iron obtained from it, nor upon its freedom from injurious elements, but also on the cost of labour and materials required to hew the ore from the earth, on its transit to the furnace, and on the fuel, flux, and labour required in smelting. Some iron ore deposits are situated at such a distance from iron and steel manufacturing centres that it would cost more to

TABLE II

PERCENTAGE ANALYSES OF THE PRINCIPAL IRON ORES

No.	Ore.	Fe_2O_3	FeO	MnO	Al_2O_3	CaO	MgO	SiO_2	P_2O_5	FeS_2	CO_2	H_2O	Insoluble Residue.	Metallic Iron.
1	Magnetite, British	62·2	16·20	0·14	2·28	2·34	0·37	0·24	0·10	0·07	—	0·34	16·26	57·01
2	,, ,,	44·4	20·0	0·16	5·20	0·6	1·0	—	0·5	0·04	—	2·5	24·2	46·63
3	,, Foreign	81·16	11·06	2·38	0·6	—	—	2·5	—	—	—	2·1	—	63·02
4	,, ,,	58·93	27·55	0·1	0·29	0·38	0·61	12·54	Trace	0·04	0·12	0·11	—	62·6
5	Hematite, Red	95·16	—	0·24	—	0·07	—	—	Trace	Trace	—	—	5·68	66·6
6	,, ,,	86·50	—	0·21	—	2·77	1·46	—	Trace	0·11	2·96	—	6·55	60·55
7	,, Brown	90·05	—	0·08	Trace	0·06	0·2	—	0·09	Trace	—	9·22	1·07	63·04
8	,, ,,	52·83	—	0·81	—	14·61	5·7	—	0·32	0·28	18·14	4·75	0·04	36·98
9	Spathic	—	55·64	Met.Mn. 2·17 2·80	—	0·92	1·77	—	—	—	38·35	—	—	43·27
10	,,	0·81	43·84	Met. Mn. 9·80 12·64	—	0·28	3·63	—	—	—	38·86	0·18	0·08	34·67
11	Clay Ironstone	—	52·04	0·92	1·3	0·53	0·85	—	0·21	0·13	32·31	0·46	11·14	40·84
12	,, ,,	1·20	35·38	0·94	0·8	2·78	2·22	—	0·48	0·18	25·41	1·11	28·0	28·76
13	Blackband Ironstone	0·23	53·82	—	—	1·51	0·28	2·0	—	—	34·39	—	7·7	41·6
14	,, ,,	—	37·07	0·23	—	6·61	7·4	2·7	0·23	Trace	36·14	—	9·8	28·83
15	Cleveland	3·6	39·92	0·95	7·86	7·44	3·82	7·12	1·86	0·11	22·85	2·97	1·64	33·62
16	,,	—	33·17	0·50	3·92	11·9	4·52	—	0·48	—	28·0	3·65	13·22	25·8
17	Bog and Lake	70·46	—	—	5·88	—	—	13·04 (Sand)	—	—	—	11·12	—	49·32
18	,, ,,	62·59	—	(MnO_2) 8·52	—	—	—	11·37	1·50	—	—	16·02	—	43·82
19	Luxemburg Ironstone	60·06	—	Trace	6·3	6·23	0·39	9·61	1·98	(SO_3) 0·17	4·88	10·45	—	42·04
20	,, ,,	42·47	—	—	5·93	9·17	0·5	27·4	1·61	(SO_3) 0·12	7·15	6·12	—	29·72
21	Bilbao Ironstone	90·5	—	1·2	—	0·634	—	1·88	—	—	—	5·8	—	62·44
22	,, ,,	77·85	—	—	1·5	0·5	—	8·5	—	—	—	10·6	—	54·5
23	Swedish, Tuolluvaare	1·41	(Fe_3O_4) 91·05	0 16	0·16	0·28	1·12	3·42	0·05	(S) 0·011	—	—	—	—
24	Erzberg, Raw	19·5	32·25	3·5	1·26	5·92	4·06	4·08	0·034	(SO_3) 0·202	27·62	0·84	—	—
25	,, Calcined	71·18	1·23	4·29	1·61	6·19	4·14	8·19	0·059	(SO_3) 0·432	2·64	0·14	—	—

Analyses by: 1, Riley; 2, Dr. Noad; 5 and 6, Dick; 7 and 8, Dick; 9, Karsten; 10, Spiller; 11, Dick; 12, Spiller; 13, Colquhoun; 14, Price and Nicholson; 15, Dick; 16, Tookey; 17, Schenck; 18, Senft; 19 and 20, Bell; 23, Dagerfors Iron Works Laboratory; 24 and 25, Oesterreichische Alpine Montan-Gesellschaft (Bauerman).

work the mine and ship the ore to the nearest market than it would be worth to manufacturers.

It is usual, wherever possible, to erect blast furnaces and steel works close to the ore mines, so that the cost of transit of ore to furnaces is reduced to a minimum.

In his book on the "Manufacture of Iron and Steel," Sir I. Lowthian Bell deals exhaustively with the various items of cost involved in the hewing of different classes of ores from the earth and with the labour and materials required to produce metallic iron from the ores. He states[1] that the average weight of Cleveland ironstone worked per man per shift of seven hours, was as follows in the years given:—

1873	1877	1880
5·05 tons	5·25 tons	5·35 tons.

The nett wages of the miner per shift, after paying for the powder and oil used, was—

	1873	1877	1882
When the selling price of iron was	£5 3*s.* 9*d.* per ton	£2 3*s.* 1½*d.* per ton	£2 3*s.* 4*d.* per ton
Nett wages per shift	7*s.*	4*s.* 10½*d.*	5*s.*

The average selling prices of Cleveland ironstone per ton of 20 cwts., delivered at Middlesbrough as a central point during the following years, were—

1870	1873	1877	1879	1883
5*s.*	7*s.*	5*s.*	4*s.* 4*d.*	5*s.*

and as it is found that 65 to 68 cwts. of Cleveland ironstone as received from the mines are required to produce 1 ton of pig iron, the cost of iron ore per ton of pig iron in 1883 was from 16*s.* 3*d.* to 17*s.*

The prices of ores vary very much at both the mines and the furnaces in different parts of the world. The hardness of the ores in some mines permits of only about 1 ton per man per day being mined, as against 5 tons or more in other mines. The cost at the furnace is also influenced by the cost of freight. We give below the prices of a few different ores delivered at the furnaces ready for smelting.

TABLE III

PRICES OF IRON ORE, 1910

Ore.		Bessemer.	Non-Bessemer.	Yield of Iron.	Remarks.
Lake Superior[2]	Old range	20/10	—	55%	2/1 to 4/2 extra according to situation of furnace.
	Mesabi	19/9½	—	55%	
	Old range	—	17/6	51·5%	
	Mesabi	—	16/8	51·5%	
Best Bilbao Rubio (at English Port)		—	22/6	50%	
Swedish Ore[3]	at Westphalia	—	19/-	66%	
	at the Rhine	—	17/5	66%	
	at English N.E. Ports	—	22/- to 25/-	60%	
Minette Ore[3]	at Westphalia	—	9/3	34·24%	
	at the Rhine	—	9/3½	34·24%	

[1] Bell, "Manufacture of Iron and Steel," p. 647.
[2] "Mineral Industry," 1910, p. 416.
[3] "Iron and Coal Trades Review," vol. 81, p. 367.

Uses of Iron Ores.—Most of the iron ores used in steel manufacture are converted first into pig iron; only a very small proportion of the ores is used for the direct manufacture of steel and for oxidising purposes in the open-hearth processes.

In 1910, the total amount of pig iron produced throughout the world was 65,860,260 metric tons;[1] the share taken in the world's production by the three important steel-producing countries being as follows:—

United States	40·4 %
Germany	22·4 %
United Kingdom	15·8 %

SECTION II

PIG IRON

The following table gives the amount of ore used by the three leading countries, and the quantities of pig iron and acid and basic steel produced during 1910:—

TABLE IV

ORE, PIG IRON AND STEEL OUTPUT DURING 1910

	Iron ore. Tons.	Pig iron. Tons.	Steel produced. Tons.
United States[2]	53,267,397	27,636,687[5]	26,094,919
Germany[3]	28,231,000	14,793,325[5]	13,482,199
Great Britain[4]	14,979,979 (1909)	10,380,212[5]	6,010,684

The annual rate of the world's output of pig iron and steel during the first ten years of the twentieth century increased each year until in 1910 it was nearly double that of the output of 1901. It is interesting to note that some countries have developed the manufacture of steel much more rapidly than others. The most serious outlook is the decline of our own country's progress. In his admirable work on the "Manufacture of Iron and Steel," published in 1882, Sir I. Lowthian Bell writes:[6] "In an industrial point of view Great Britain founded its greatness as an iron-making centre, such as it was in the first three decades of the present century, on the least valuable of its ores. The furnaces of Wales and Staffordshire for many years were supplied almost exclusively from nodules, and from thin bands of clay ironstones, obtained from the shales of the coal-measures." If Sir I. Lowthian Bell were alive to-day he would doubtless trace our nation's greatness to its continued use of the ores of this and other countries, but he would be obliged to admit that the industrial supremacy which Great Britain enjoyed in the decades to which he referred, could no longer be claimed by this country. From Table V. it will be observed that the U.S.A. leads the world's output, Germany following closely, while Great Britain stands still.

[1] "Mineral Industry," 1910, p. 381.
[2] and [5] "Mineral Industry," 1910, pp. 3, 5, 381.
[3] and [4] "Iron and Coal Trades Review," vol. 82, pp. 580, 775, 836.
[6] Bell, "Manufacture of Iron and Steel," p. 646.

TABLE V

WORLD'S PRODUCTION OF PIG IRON AND STEEL[1]

(In metric tons. 1 ton = 2204 lbs.)

Country.	Pig Iron.			Steel.		
	1901.	1906.	1910.	1901.	1906.	1910.
Austria and Hungary .	1,300,000	1,403,500	2,010,000	1,142,500	1,195,000	2,154,832
Belgium . .	765,420	1,431,160	1,803,500	526,670	1,185,660	1,449,500
Canada . . .	248,896	550,618	752,053	26,501	515,200	835,487
France . . .	2,388,823	3,319,032	4,032,459	1,425,351	2,371,377	3,506,497
Germany . .	7,785,887	12,478,067	14,793,325	6,394,222	11,135,085	13,698,638
Italy. . . .	25,000	30,450	215,000	121,300	109,000	635,000
Russia . . .	2,869,306	2,350,000	2,740,000	2,230,000	1,763,000	2,350,000
Spain . . .	294,118	387,500	367,000	122,954	251,600	219,500
Sweden . . .	528,375	552,250	604,300	269,897	351,900	468,600
United Kingdom	7,977,459	10,311,778	10,380,212	5,096,301	6,565,670	6,106,856
United States .	16,132,408	25,706,882	27,636,687	13,689,173	23,772,506	26,512,437
All other countries . .	635,000	650,000	525,000	405,000	420,000	315,000
Totals . . .	40,950,692	59,074,861	65,860,260	31,449,869	49,635,998	58,252,234

Analyses of Pig Iron.—Pig iron analyses are almost as numerous[2] as the iron ores from which they are made, but generally for purposes of steel manufacture they can be divided into seven groups:—

1. Pig irons known mostly as Forge pigs.
2. ,, for Bessemer Basic steel manufacture.
3. ,, ,, ,, Acid ,, ,,
4. ,, ,, Open-hearth Basic steel manufacture.
5. ,, ,, ,, ,, Acid ,, ,,
6. ,, ,, Electric process of ,, ,,
7. ,, ,, Duplex processes of ,, ,,

Under each of these groups many subdivisions can be made, each manufacturer producing several kinds of pig iron known by special brand names, which indicate to the users a degree of purity adapted for the different classes of steel required.

Below we give the following tables of analyses in the order named above, instead of grouping all the pig irons in one table.

[1] "Mineral Industry," 1910, pp. 381, 382.

[2] N. Lilienberg gives analyses of 137 brands of American pig irons in "Bihang till Jernkontorets Annaler," 1903, pp. 202–206.

TABLE VI

1. Pig iron from which bar iron or wrought iron is produced, either by means of puddling or other process, and afterwards rolled into bars for use in the crucible process.

No 1.	Locality.	Carbon %	Silicon %	Manganese %	Phosphorus %	Sulphur %	Copper %	Arsenic %
1	Styrian	3·5–4·2	0·11–0·24	0·8–2·4	0·03–0·07	0·02	0·005	—
2	Dannemora (Swedish)	4·5	0·08	1·77	0·018	0·015	0·015	0·035
3	Goldsmedhütte . .	4·0	0·73	0·11	0·051	—	—	—
4	From Erzberg ore .	3·57	0·25	1·37	0·04	0·04	—	—

1. "Proceedings Institute of Civil Engineers," vol. cxxii, p. 470.
2 and 3. "Journal Iron and Steel Institute," 1905, II, p. 686.
4. "Journal Iron and Steel Institute," 1907, III, p. 35.

TABLE VII

2. Basic Bessemer Pig Iron

No.	Locality.	Carbon %	Silicon %	Manganese %	Phosphorus %	Sulphur %
1	Yorkshire.	2·5	0·56	1·4	2·75	0·068
2	,, ...	2·5	1·10	1·5	2·75	0·06
3	N. Wales	—	0·6	2·0	2·0	0·07
4	Staffordshire . . .	—	1·0	2·3	3·3	0·05
5	East Coast . . .	3·1	1·0	1·2	1·8	0·05
6	,, ,, ...	—	0·55	2·25	2·7	0·05
7	,, ,, ...	—	0·5 to 1·0	1·5 to 2·0	1·8 to 3·0	0·06 to 0·08
8	,, ,, ...	—	1·5 to 3·0	0·5 to 0·75	1·45 to 1·55	0·04 to 0·06
9	German— . .	—	0·75	1·5	2·0	0·5
10	Luxemburg .	—	0·1 to 0·8	1·0 to 1·5	1·5 to 2·5	0·13 to 0·6
11	Lorraine . .	—	1·19	0·63	1·86	0·05
12		—	1·32	0·61	1·75	0·08
13		—	0·42	1·18	2·47	0·13
14	Austria— . . .	—	0·54	1·0	1·95	0·23
15	Witkowitz . . .	—	0·11	1·16	3·46	0·09
16		—	0·62	1·38	2·0	0·08
17		—	0·79	—	0·9	—

7 and 8. "Journal Iron and Steel Institute," 1907, I, p. 106.
9–17. Wedding, "Basic Process," p. 92.

Steel makers usually mix one or two brands together when making up a charge, according to the quality of steel required.

TABLE VIII

3. Acid Bessemer Pig Iron

No.	Locality.	Carbon %	Silicon %	Manganese %	Phosphorus %	Sulphur %
1	Scotch	4·0	3·5 to 3·8	0·8	0·03	0·03
2	,, ...	3·15	3·0	1·45	0·049	0·025
3	East Coast . . .	4·0	2·8	1·065	0·04	0·025
4	,, ,, . . .	4·10	2·5	—	0·05	0·03
5	,, ,, . . .	3·8	3·0	1·32	0·04	0·03
6	West Coast . . .	3·93	1·0 to 3·0	0·5 to 0·8	0·03	Trace to 0·03
7	,, ,, . . .	3·7	3·0	0·7	0·03 to 0·01	0·01
8	S. Wales	3·67	2·5	0·5	0·06	0·03
9	German	3·76	2·52	3·9	0·07	0·03
10	American (Chateaugay)	—	2·5	—	0·025	0·015
11	American . . .	3·8 to 4·5	1·8 to 3·0	0·5 to 2·0	0·06 max.	0·05 max.
12	Swedish	4·0 to 4·5	1·0	1·5 to 4	0·03	0·03

9. "Journal Iron and Steel Institute," 1908, I, p. 322.
10. Pilling & Crane. New York.
11. From paper read by Mr. Simonson, General Manager of the Tropenas Converter Co., at a meeting of the Philadelphia Foundrymen's Association, Jan. 6th, 1909.
12. Åkerman, "American Inst. of Mining Engineers," vol. xxx, p. 268.

TABLE IX

4. Basic Open-hearth Pig Iron

No.	Locality.	Carbon %	Silicon %	Manganese %	Phosphorus %	Sulphur %
1	Lincolnshire . . .	—	0·75	1·5 to 2·0	1·5 to 2·0	0·07
2	Yorkshire. . . .	2·5	0·357	1·68	2·63	0·042
3	East Coast . . .	—	0·75	1·5	1·5	0·07
4	,, ,, . . .	3·1	1·0	1·2	1·8	0·05
5	N. Wales . . .	3·71	0·9	2·98	2·78	0·035
6	,, ...	—	0·7	2·5	2·0	0·c6
7	U.S.A.	3·5 to 4·0	0·5 to 1·0	0·0 to 0·5	0·5 to 1·0	0·05 to 0·1
8	U.S.A. (Talbot Furnace)	3·7	1·0	0·4	0·9	0·06
9	Belgium	3·0	0·2	1·5	2·2	0·04

2. "Colliery Guardian," vol. lx, p. 103.
7 and 8. "Iron Age," vol. lxx, Aug. 7th, p. 21.
9. "Journal of West of Scotland Iron and Steel Institute," vol. vii.

TABLE X.

5. Acid Open-hearth Pig Iron

These pig irons differ very little from the acid Bessemer pig irons, and are used with high and low content of silicon, according to the amount of mild steel scrap used.

No.	Locality.	Carbon %	Silicon %	Manganese %	Phosphorus %	Sulphur %
1	Scotch	3·5	2·5 to 3·0	0·7 to 0·8	0·04 to 0·05	0·02 to 0·03
2	West Coast . . .	3·67	1·0 to 3·0	0·5 to 0·8	0·03	Trace to 0·03
3	" " . . .	3·65	2·5	0·7	0·04	0·02
4	East Coast . . .	4·0	2·5	1·0	0·04	0·02
5	S. Wales	3·3	2·1	1·15	0·045	0·03
6	"	3·61	2·0	0·5	0·06	0·05
7	U.S.A. (Chateaugay)	—	2·0 to 2·5	—	0·02 to 0·03	0·013 to 0·017

TABLE XI

6. Various Pig Irons for Electric Process

No.	Locality.	Carbon %	Silicon %	Manganese %	Phosphorus %	Sulphur %	Copper %	Arsenic %
1	Herräng pig iron. .	—	0·15	0·025	0·009	0·01	—	—
2	Dannemora pig iron .	4·5	0·08	1·77	0·018	0·015	0·015	0·035
3	Goldsmedhütte . .	4·0	0·73	0·11	0·051	—	—	—

1. "Transactions of the American Electrochemical Society," vol. xv, p. 180.
2 and 3. "Oesterreichische Zeitschrift für Berg- und Hütterwesen," vol. iii, p. 447.

TABLE XII

7. Pig Iron used in the Open-hearth Molten Metal Processes

(Duplex, pig and ore, and continuous processes.)

No.	Process.	Carbon %	Silicon %	Manganese %	Phosphorus %	Sulphur %
1	Bessemer and open-hearth "Witkowitz," 1878	3·7	1·2	2·7	0·2	0·02
2	Daelen - Pscholka process	3·5	1·5	2·2	—	—
3	Open-hearth Bertrand Thiel	3·25	0·654	2·4	2·42	0·076
4	Monell process . .	3·9–4·1	0·5–0·9	0·8–0·9	0·5–0·8	0·04–0·09
5	Surzycki	up to 3·0	0·8–1·9	0·6–1·5	0·5–0·8	0·02–0·10
6	Talbot process, U.S.A.[1]	4·0	1·0–1·25	0·65	0·1	0·06
7	Talbot process, Frodingham	—	0·75–1·25	2·0	1·75–2·0	0·06

1, 2, and 4. "Iron Age," vol. 76, p. 609.
3. "Journal Iron and Steel Institute," 1905, I, p. 127.
5. *Ibid.*, 1905, I, p. 113.
6. *Ibid.*, 1903, I, p. 59.
7. *Ibid.*, 1903, I, p. 63.

[1] Pig irons in the U.S.A. are usually classified as Bessemer or non-Bessemer, according to whether they contain less or more than 0·1 per cent. P.

With the pig irons referred to in Tables VI to XII, mixtures of scrap steel and iron, iron ore, scale, etc., are used in accordance with the kind of process employed. These mixtures are given in the charges detailed under the sections relating to each process.

Cost of Pig Iron.—In producing pig iron, the cost varies according to the price paid for the ore at the blast furnace, the prices and amounts of fuel and flux required per ton of iron smelted, and the price of labour, kind of furnace used, and quality of pig required.

Some ores are so rich in calcium as to require little or no flux, while with other ores 20 to 30 cwts. of limestone are used in producing 1 ton of pig iron.[1]

The coke required per ton of pig iron melted equals from 1 to $1\frac{1}{2}$ tons.

The prices of labour and kind of plant used vary in different countries, and it would be difficult to give a comparison of costs of production which could be regarded as accurate.[2] Sir I. Lowthian Bell gives a table showing the comparative costs of coke (or raw coal), ore, and limestone required to produce one ton of pig iron in various localities, calculated upon the selling prices of the materials used—given in percentages of No. 3 Cleveland pig.

At the time in question, Cleveland No. 3 was selling at 37*s.* 6*d.* per ton (in June, 1912, the price was 57*s.* 3*d.*), and for hematite iron in Cumberland and Lancashire the ore is taken at 13*s.* per ton. The following are the percentages :—

TABLE XIII

COMPARATIVE COST OF PIG IRON PRODUCTION

Country and district.	Comparative costs of coke (or raw coal), ore, and limestone required to produce 1 ton of pig iron, based on Cleveland No. 3 as 100.		
	Cleveland No. 3.	Forge iron.	Bessemer.
British—			
Middlesbrough	100	98	123
Northumberland	—	—	120
South Wales	—	120	125
Scotch mixed	112	112	112
Germany—			
Western Germany	100	85	—
Luxemburg	—	90	—
Ilsede	—	80	—
Westphalia	140	Common 103 Best 135	140
France—			
Dept. of Meurthe	137	110	—
Neighbourhood of Nancy	—	103 and 90	—
Nancy, South	129	123	214
Neighbourhood of St. Etienne	—	—	221 to 230 (In 1867 : 212)
Central France	—	156 to 187	—
Belgium	120	102	140

[1] Bell, "Manufacture of Iron and Steel," p. 673.

[2] Hugo Carlsson gives an account of the production of pig iron in Sweden in the "Tecknisk Tidskrift," Stockholm, 1906, General Section, pp. 125–127, in which important details on cheap production are given.

Table XIV gives the average cost of pig iron per ton produced in the United States of America during the years 1902–1906, from statistics prepared by Commissioner Knox of the Bureau of Corporations investigating steel costs in typical plants.

TABLE XIV

COST OF PRODUCING BESSEMER PIG IRON (ALL DISTRICTS), DURING 1902–1906 IN U.S.A.[1]

Total tons produced, 51,902,699.

Items of cost.	Price per ton.	Cost per ton of pig iron.
	s. d.	£ s. d.
Nett total metallic mixture	16 6½	1 10 5
Coke	14 0½	0 16 2½
Limestone	—	0 1 9½
Labour[2]	—	0 3 2½
Steam	—	0 0 6
Materials in repairs and maintenance	—	0 0 8
Supplies and tools	—	0 0 6½
Miscellaneous and general works expenses	—	0 1 2
General expense	—	0 1 6
Refining and renewals	—	0 0 9
Depreciation	—	0 1 7½
	Total	£2 18 4½

Selling Prices of Pig Iron.—As a rule, steel manufacturers contract for the supply of pig iron on the most favourable basis of supply for periods of 3, 6, 9, and 12 months at a fixed price. The market selling prices, however, fluctuate very considerably. Average selling prices for British, American, and German pig iron during 1910 are given below.

AVERAGE PRICES.

Year.	British. Cleveland.		American. Pittsburg.		Germany. Siegun.	
	Acid.	Basic.	Acid.	Basic.	Acid.	Basic.
	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.
1910	66 0	52 6	71 3	65 0½	70 0	58 6

[1] "Iron Age," vol. 82, p. 1987.

[2] The item of labour does not include, for much of the tonnage, the labour of unloading raw materials and producing steam, which some of the companies include in the cost of raw materials, and in the item "steam."

The following table shows the fluctuation in the prices during 1910 :—

TABLE XV

FLUCTUATION IN PRICES OF PIG IRON

No.		Dec. 29th, 1909. Per ton.	Dec. 28th, 1910. Per ton.	Changes. Per ton.
		s. *d.*	*s.* *d.*	*s.* *d.*
	American (at tide water)			
1	No. 2x Foundry, Philadelphia	79 2	64 7	fall 14 7
2	No. 2 Southern, New York	78 1½	64 7	fall 13 6½
3	Basic, Philadelphia .	78 1½	61 5½	fall 16 8
	British—			
4	Acid pig	62*s.* 6*d.* to 63*s.*	64*s.* 6*d.* to 66*s.*	increase 2*s.* to 3*s.*

1, 2, and 3, "Mineral Industry," 1910, p. 373.

SECTION III

REFRACTORY MATERIALS

Refractory materials, such as are used in the various processes of steel manufacture, abound in different parts of the world. Chief among them are the various clays, consisting principally of hydrated silica and alumina in different proportions associated with numerous other substances, according to the locality in which they are found. The refractoriness, or fire-resisting characteristic of the clays differs in the raw state as well as in the manufactured condition, such as in Fireclays, Fireclay Bricks, Silica Cements, Silica Bricks, Ganister, etc. Other refractory materials which come more prominently into use in the basic process are Lime, Magnesite, Magnesian Limestone (Dolomite, which contains the carbonates of both Magnesia and Lime), Chromite, a double oxide of Iron and Chromium, Bauxite, an oxide of Iron and Alumina, besides many other refractories having different names applied to them, due to the presence of greater or lesser proportions of one or other of the substances named.

As the result of modern research, the manufacture of refractory materials has been much improved. Experimenters have not only analysed the various clays suitable for the linings of steel and other auxiliary furnaces, but have found the fusing-points of clays when associated with different proportions of other substances. They have also indicated in what way the various operations in the manufacture of bricks from refractory materials influence the durability of the linings in furnaces when exposed to high temperatures.

All practical steel makers have at one time or another experienced some difficulty when by accident or irregularity in the quality a poor refractory has been supplied in place of the usual consignments of materials. The loss and trouble with slaggy heats, and rapid wear of linings, have not promoted the best feelings in the steel melter, nor always reliability in the quality of the steel produced. Standardisation of raw and finished products by chemical, refractory, mechanical, and density tests minimise to a very considerable degree the practical and very real troubles in steelworks.

Classes of Refractory Materials.—Refractory materials may be divided into three distinct classes, as far as they pertain to steel manufacture.

1. Silicious, or acid.
2. Non-Silicious, or basic.
3. Non-Silicious and Non-Basic, or neutral.

The silicious materials are used in what are known as the acid processes; the basic materials in the basic processes; and the neutral materials are used in conjunction with both, in such furnaces where the basic materials form the hearth of the furnace and the acid materials the walls and roof, between which a neutral course of brickwork is fitted.

Silicious Materials

General Description.—Silicious materials, as used in steel manufacture, are supplied as fireclays; ganister (a name originally given to a highly silicious sandstone found near Sheffield, but now given to silicious rock which contains a little clay, found anywhere, and which can be suitably ground and mixed in such proportions as to produce a refractory lining for converters, cupolas, and like furnaces); silica cement (a material mixed with water and used as mortar for brick joints); fireclay bricks, and silica bricks. The brands given to the manufactured bricks, cements and clays are many, but the raw materials from which they are produced, as well as the method of manufacture adopted, have a very important bearing upon the quality and price of the materials. The following table gives the analyses of British, American, and Continental fireclays, which are fairly representative :—

TABLE XVI

Percentage Analyses of Fireclays—British, American, and Continental

No.	Locality.	SiO_2	Al_2O_3	FeO	Fe_2O_3	CaO	MgO	Alkalies.	TiO_2	H_2O and organic matter.	Total.
1	Newcastle-on-Tyne .	55·50	27·75	2·01		0·67	0·75	2·63	—	10·53	98·84
2	Dowlais (South Wales)	67·12	21·18	—	1·85	0·32	0·84	2·02	—	7·11	100·44
3	Stourbridge . . .	63·30	23·30	1·8	—	0·73	—	—	—	10·3	99·43
4	Staffordshire . . .	51·80	30·40	4·14	—	—	0·50	trace	—	13·11	99·95
5	Glasgow	66·16	22·54	5·31	—	1·42	trace	—	—	3·14	98·57
6	Ireland	79·40	12·25	—	1·30	0·50	—	—	—	5·20	98·65
7	Belgium	57·08	30·04	—	0·67	0·56	0·18	2·10	—	8·45	99·08
8	Schöningen, Hanover	59·01	24·26	—	4·04	1·32	0·72	1·20	—	10·24	100·79
9	Hayange, Moselle .	66·10	19·80	—	6·30	—	—	—	—	7·50	99·70
10	Vallend near Coblenz	55·46	31·74	—	0·59	0·19	0·14	3·17	—	9·37	100·66
11	Bibbville, Alabama .	74·25	17·25	—	1·19	0·40	trace	0·52	—	6·30	99·91
12	Mecca, Indiana . .	63·00	23·57	0·46	1·87	0·44	0·89	2·69	1·10	6·45	100·47
13	New Brighton, Penn.	61·75	23·66	1·93	—	0·45	0·35	2·41	1·78	7·20	99·53

1, Hugh Taylor; 2, E. Riley; 3, C. Tookey; 4, T. H. Henry; 5, J. Brown; 6, T. H. Henry; 7, Bishof; 8, Strong; 9, Salvétat; 11, 12, and 13, Standard American Clays, N. Ries, Professional paper No. 11, U.S.A. Geological Survey.

It will be observed that in all varieties, the main constituents of each are silica and alumina. Pure alumina silicate ($Al_2O_3 + 2SiO_2 + 2H_2O$), which is highly refractory, should contain 46 per cent. of Al_2O_3 in the calcined state, but

this is purely theoretical and cannot be obtained in practice. It is stated[1] that firebricks which are stipulated to contain this amount, must be made from clays mixed with bauxite, which produces fusibility at high temperature and much shrinkage in cooling.

Objectionable substances in Fireclays when used as Refractories.—The most objectionable substances in fireclays when the latter are used in furnaces, are those which tend to produce fusibility and undue expansion and contraction. Perhaps alkalies and oxides of iron give most trouble in these directions. It is important that the total alkalies should not exceed 2 per cent. in fireclay bricks, and as far as possible the percentages should not be more than 1 per cent. In high silica bricks the presence of even 1 per cent. is objectionable, and bricks entirely free from alkalies give the best results. Iron oxides are not so injurious, even when present up to 2 to 3 per cent., if the alkalies are kept low. In the following table is given the fusion-point of fine washed clay and also the temperatures at which the same clay will fuse when mixed with other substances :—

TABLE XVII

TABLE GIVING THE FUSION POINT OF COMPOUNDS FORMED OF FINE WASHED CLAY AND OTHER MATERIALS[2]

Substances added to fine washed clay.	Per cent.	Fusion point. Degrees C.
Carbonate of lithium	20	1330
Magnesium carbonate	10	1380
Manganese dioxide	20	1400
Calcium carbonate	20	1450
Iron oxide	20	1610
Infusional slag	50	1700
White glass	20	1710
Titanium oxide	20	1730
Zinc oxide	20	1760
Lead oxide	20	1770
Unmixed clay	—	1780
Felspar	20	1810[3]
Alumina	20	1810
Chromic oxide	15	1810

The limit of refractoriness for the highest grade of fireclay brick is given by W. A. Stanton[4] as 3350° F. (1843° C.). He states that only one or two brands can stand this temperature, and that for regular work 3000° F. to 3100° F. is the highest working temperature best fireclay bricks will stand. The temperatures are usually found by the standard Seger cones. In experiments conducted by Bondouard,[5] he found that the melting-point of pure silica was 1830° C., but it was reduced from 1830° C. to 1690° C. when the silica was mixed with 14·5 per cent. of alumina. As the alumina was increased beyond 14·5 per cent. the melting-point also increased, until with 63 per cent. of alumina and 37 per cent. of silica, the melting temperature reached 1890° C.

[1] "Stahl und Eisen," vol. xxiii, p. 421.

[2] "Revue de Métallurgie," 1904, II, p. 92.

[3] It is pointed out that there must be some error with the result of the felspar mixture, as the amount added should give 3 per cent. of potash and thereby lower the melting-point.

[4] U.S.A. "Geological Survey Bulletin," No. 256, pp. 77–78.

[5] "Journal Iron and Steel Institute," 1906, IV, p. 751.

Analyses of Fireclay and Silica Bricks.—The following tables give typical percentage analyses of fireclay and silica bricks :—

TABLE XVIII

ANALYSES OF FIRECLAY BRICKS

	1.	2.
SiO_2	63·09	71·02
Al_2O_3	29·09	26·47
CaO	0·42	Trace
MgO	0·66	0·44
FeO	—	Trace
Fe_2O_3	2·88	0·80
Alkalies	2·23	0·92
TiO_2	2·21	Trace of S.

1, Dowlais, by E. Riley. 2, Devonshire, by J. A. Phillips.

TABLE XIX

PERCENTAGE ANALYSES OF SILICA BRICKS

	1.	2.
SiO_2	98·31	96·73
Al_2O_3	0·72	1·39
FeO	0·18	0·48
CaO	0·22	0·19
Alkalies	0·14	0·20
H_2O, combined	0·35	0·50

1, Phillips, "Elements of Metallurgy," p. 126. 2, *Ibid.*, p. 127.

Opinion differs as to the best quality of silica bricks, as the quality does not only depend upon the high temperature which can be attained before fusion, but upon other factors, such as chipping too freely when subjected to intermittent use. Silica bricks made from Welsh clay, particularly the "Dinas" clay, find great favour in furnaces where high temperatures are required.

Ganister.—Perhaps ganister is more largely used in the Bessemer acid-lined converters for making and repairing the linings, than for any other furnaces. It is also used regularly for patching cupolas for melting iron and steel scrap for converter metal, as well as in some crucible furnace linings. Ganister rock varies in quality according to where it is found. Even in the same district, hard and soft varieties are quarried. It is somewhat similar in composition to "Dinas" rock, and good qualities are found near the coal seams in Yorkshire and other parts of the country. Sheffield varieties of ganister are much used in steel manufacture, as they have a very high refractory character, and set like stone when exposed to high temperatures. The art of mixing has a very great influence on the properties. Some grades of ganister contain too much alumina and "run" at moderately high temperatures, while others have too much silica without sufficient bond, and "frit."

The following percentage analyses may be taken as typical of the best ganisters :—

TABLE XX

COMPOSITION OF GOOD GANISTER FOR FURNACE LININGS

	1.	2.
Silica	88·36	89·37
Alumina	7·00	6·36
Oxide of iron	2·00	1·73
Lime	0·22	0·70
Magnesia	0·15	0·36
Alkalies	—	—
Water or loss on calcining	2·32	2·88
Total	100·05	101·40

1, Lowood (Snelus). 2, Riley.

For some purposes ganister containing about 80 per cent. of SiO_2 and 10 per cent. to 15 per cent. of Al_2O_3 is used with good results.

Expansion and Contraction of Fireclay Bricks.—Fireclay and high silica bricks vary in degree of expansion and contraction when exposed to heat, according to the composition of the materials of which they are made. In furnace construction, allowances must be made for expansion when building the linings, and most careful attention is always necessary when heating furnaces for the first time after being lined with either fireclay or high silica bricks. When the bricks expand very much, they do not always come back to their original size, and sometimes cracks in brickwork or rifts in joints are observed if the

TABLE XXI

Refractory materials.	Purpose for which used.	Cost per 1000.	Cost per ton.	Remarks.
Ganister	Cupola patching, converter patching and lining	—	12*s*. to 13*s*.	The prices given are for materials sold in this country
Ganister, fine	Crucible furnace patching	—	18*s*. to 20*s*.	
Silica cement	Brickwork joints of all acid lined furnaces	—	35*s*. to 40*s*.	
Fireclay, ground	Joints of cupola linings	—	9*s*. to 12*s*.	
Fireclay bricks				
Ordinary sizes	Cupolas	55*s*. to 70*s*.		
Specials	,,	1*d*. to 8*d*. each		
Silica bricks (high grade)				
Ordinary sizes	Lining steel melting furnaces	150*s*. to 160*s*.		
Silica bricks (lower grade)				
Ordinary sizes	Lining steel melting furnaces	90*s*. to 100*s*.		
Silica blocks, specials	For crucible furnaces, converters, open-hearth and electric furnaces	Prices vary according to design and weight from a few pence to several shillings each block		

greatest care has not been taken to liberate part of the framework which may enclose the lining.

Several experiments have been made to try and measure the amount of expansion and contraction that takes place in fireclay and silica bricks when exposed to heat. The results, however, are so variable with different clays that no reliable figures can be given. Good and definite brands of fireclay or silica bricks can be relied upon with an amount of certainty for all practical purposes, which enable the necessary allowances to be made for expansion in furnace building.

Cost of Silicious Refractory Materials.—On p. 21 (Table XXI) is given a list of the more important silicious refractory materials with their prices and uses.

Basic Materials

General Description.—Since Thomas patented his composition for producing basic linings for steel converters and other furnaces, many other patent mixtures have been tried and used. Methods of refining the materials used in making the various basic bricks have also been numerous. The basic materials mostly used for lining steel furnaces may be classified thus:—

1. Dolomite.
2. Magnesite.
3. Bauxite.
4. Chromite.
5. Limestone and Lime.

1. **Dolomite.**—Dolomite in the crude state varies in composition, but contains principally lime and magnesia, with small proportions of silica, alumina, and oxides of iron. The following table gives the percentage analyses of various dolomites:—

TABLE XXII

Analyses of Dolomites

	1.	2.	3.	4.
Lime	29·86	31·36	28·52	—
Magnesia	20·17	19·28	17·56	—
Ferric oxide	—	—	1·78	0·37 (with alumina)
Alumina	—	1·5	2·57	
Calcium carbonate	—	—	—	58·8
Carbon dioxide	45·64	45·86	43·05	—
Silica	4·34	2·0	6·5	0·55
Magnesium carbonate	—	—	—	41·35
Manganous oxide	—	—	—	traces

1, Used at Creusot; 2, Used at Hörde; 3, Used at Middlesbrough; 4, Analysis made at Ironworks at Kisel in Ural. Analyses 1, 2, and 3 Wedding, "Basic Process," p. 40. Analysis 4, "Journal Iron and Steel Institute," 1904, II, p. 477.

When the crude material is crushed to about the size of ordinary road macadam it is burnt in basic lined kilns or in cupolas similarly lined. The calcined shrunk dolomite contains from 56 per cent. to 58 per cent. of lime, with 35 per cent. to 38 per cent. of magnesia, and is crushed in mills until the largest pieces pass through a mesh of about $\frac{3}{16}$ inch to $\frac{1}{4}$ inch. The crushed material is then mixed with hot tar, from which all the water has been expelled. The

amount of tar used varies at different works, but the average amount by weight is about 10 per cent. The following percentages of tar used at the places named are given by Wedding[1] :—

At Alexandrowsky in Russia	17 to 18 %
„ Hörde, Germany	10 „ 12 %
„ Creusot, France	10 „ 11 %
„ Middlesbrough, England	9 „ 10 %
„ The Rhein Steel Works, Germany . . .	8 „ 9 %
„ Rothe-Erde, Germany	7%

Whatever proportion of tar is used, no more is required than will enable the material to unite in a compact mass when pressed into moulds when bricks are required, or when being rammed to form the linings and bottoms of converters and other furnaces.

Dolomite Bricks.—Dolomite bricks are made from finely ground calcined dolomite, usually mixed with a small proportion of clay or tar, to make a material sufficiently plastic which will hold together when thoroughly burned and when subsequently exposed to the varying changes of temperature in actual furnace work. The methods of calcining, crushing, grinding, and moulding were rather crude when dolomite was first found so valuable as a lining for converters, but now every large works has, as a rule, its own crushing, grinding, and moulding plant, all power driven. Bricks made by power presses wear much better and take less time to fit into a converter than the hand-made bricks, which were not so regular in size or density. Bottoms for converters are also power rammed, thus saving time and expense.

The fuel consumed in calcining dolomite varies from 50 per cent. of the weight of the product to over twice the weight, according to the kind of dolomite treated. The fuel consumed in burning the bricks equals from 40 per cent. to 50 per cent. of the weight of bricks burned. The shrinkage of the bricks, even with the most careful air drying and slow heating in kilns, is from 24 per cent. to 50 per cent.[2]

2. **Magnesite.**—Magnesite is an excellent basic refractory material, although rather more expensive than dolomite. The principal sources from which it is derived are Austria-Hungary, Greece, India, and the U.S.A.

Magnesite is found in nature associated with many other substances, but is only used for furnace linings when the silica contained in it is not present to any marked degree.

Table XXIII (p. 24) gives the analyses of magnesite found in various parts of the world.

Pure magnesium carbonate contains 52·4 % of CO_2 + 47·6 % of MgO. The amorphous magnesite is an almost pure carbonate of magnesium containing 98 % $MgCO_3$. The principal deposits in Europe are found in the Island of Eubœa (Greece). Eubœan magnesite is said to command a higher price than that from other localities.[3] The price paid per ton of burnt magnesite in 1912 averaged from £4 to £5. The material in the crude state at the mines in California was 8 dollars (33*s.* 4*d.*) per ton, and 35 dollars (145*s.* 10*d.*) per ton ground and calcined, 1911.[4] In 1885, 800 tons of magnesite were shipped to the U.S.A. from Europe, and the first basic steel was made in 1886. In 1911, 238,209 tons of magnesite were consumed in the U.S.A., 232,209 tons of which were imported. This gives some idea of the magnitude of the demand. Owing

[1] Wedding, "Basic Process," p. 59.
[2] *Ibid.*, p. 34.
[3] "Journal Iron and Steel Institute," 1912, I, p. 456.
[4] "Mineral Industry," 1911, p. 497.

to the severe rejections in the quarry and the shrinkage in weight in calcining, it is necessary to quarry 5 tons of rock for every ton of magnesite shipped.[1]

TABLE XXIII

ANALYSES OF MAGNESITE[2]

	SiO_2 %	Al_2O_3 and Fe_2O_3 %	CaO %	CO_2 %	MgO %	$MgCO_3$ %
Greece	1 to 2	1·75 to 3·2	1·1 to 3·2	—	—	92 to 98
Elba	8·5	Trace	3·5	—	41·0	—
Transvaal . . .	2·3	0·8	—	49·8	45·3	—
New South Wales .	0·42	0·54	Nil	—	—	99·01
New Caledonia . .	0·8	0·8	3·3	51·5	42·4	—
Silesia	5·6	0·85	0·12	—	—	93·0
Hungary	0·75	3·50	1·2	50·0	45·0	—
Lower California .	Trace	0·21	0·43	—	—	93·36
Allin, B.C. . . .	45·7	5·10	—	27·0	22·0	—
Margarita Venezuela	0·2	0·15	0·56	51·6	46·93	98·04
India	2·6	1·91	1·53	—	—	93·94

Magnesite Bricks.—Magnesite bricks are always made from the burnt magnesite. As the material is mined, it is broken into lumps and sorted, to remove, as far as possible, sand, lime, clay, and other injurious substances which may be associated with the magnesite. Shaft furnaces are used chiefly for burning the material. The temperature for burning pure magnesite is practically 1700° C., but when it contains 3 per cent. to 4 per cent. of iron oxides, the temperature is about 1400° C.,[3] and the colour of the burnt magnesite is dark brown or black. Coal is used for burning in preference to coke, and amounts to about 30 per cent. to 40 per cent. by weight of the burnt magnesite. When the material is burnt it is removed from the kilns, cooled with water, and allowed to weather for about 4 weeks, after which it is sorted and ground to about 1 mm. gauge in a ball or Chilian mill. The finely ground powder is usually mixed with some binder such as tar, and moulded into blocks in hydraulic presses with a pressure ranging from 80 to 300 atmospheres. Bricks made of good magnesite do not require any binder.

When moulded, the bricks are allowed to dry naturally for a few weeks, and then dried at about 20° C. At this temperature cracks reveal if any lime and other objectionable substances are present. After careful drying at 20° C., they are placed in a muffle furnace such as the Mendheim type, and burned for twenty-four hours, consuming about 30 per cent. of fuel in the operation. The shrinkage of the ordinary brick when properly fired does not exceed 1 to 2 mm. If they get distorted or are not uniform they are reground in the mills.

Magnesite bricks containing less than 2 per cent. of iron will withstand a temperature of about 2000° C.

The following is an analysis[4] of magnesite brick made from magnesite at Snarum, Southern Norway:—

MgO	CaO	FeO	Al_2O_3	MnO	SiO_2	P_2O_5	S
83·6	0·0	4·6	2·0	0·05	9·3	0·046	0·003 per cent.

Uses of Magnesite.—Magnesite is principally used for forming the bottoms and sides of basic open-hearth furnaces. The sides are built from 15 to 18

[1] Handbook, "Harbison-Walker Refractories Co.," Pittsburgh, Pa., p. 11.
[2] "Mineral Industry," 1911, p. 498.
[3] *Ibid.*, p. 499.
[4] "Journal Iron and Steel Institute," 1905, II, p. 566.

inches above the bottom of the charging-doors. Magnesite bricks are also used in different parts of the open-hearth furnaces around the door-jambs and tapping-holes, in the bulkheads of the ports, and in the first two or three rows of chequers in the regenerators. They are also used along the slag-line of metal-mixers instead of fireclay bricks.

Magnesite cement is used for setting magnesite bricks.

In lining furnaces with these bricks it is advisable to use a course of silica or other high-grade refractory between the plate of the furnace and the first course of magnesite bricks, as the latter, being a very good conductor of heat, might injure the platework if placed directly against same.

Magnesite bricks give the best results in furnaces which are used continuously. If subjected to sudden cooling by air, water, or oil, it will cause them to shatter and fall to pieces.

3. **Bauxite.**—This substance is composed chiefly of alumina, and when calcined at nearly 1400° C. it shrinks considerably; but when ground and mixed with a small percentage of fireclay, sodium silicate, or lime, can be made into a brick or tile. The following analyses of white and red bauxite show the variation in its composition:—

TABLE XXIV

BAUXITE FROM DIFFERENT LOCALITIES

	1.				2.	3.	
	White Bauxite.		Red Bauxite.		Arkansas U.S.A.	India.	
	Dried at 100° C. %	Undried. %	Dried at 100° C. %	Undried. %	%	Nagpur. %	Madras. %
Al_2O_3	59·8	59·6	59·9	58·6	87·3	64·64	35·38
Fe_2O_3	1·7	1·2	23·9	24·1	1·43	6·21	34·34
TiO_2	4·4	4·3	3·6	3·7	—	3·3	0·1
SiO_2	14·1	14·3	1·3	1·8	6·40	1·79	10·75
CaO	—	—	—	—	—	0·04	0·4
MgO	—	—	—	—	—	0·02	—
H_2O	20·0	20·6	11·1	11·8	—	24·0	19·0

1. Composition of white and red varieties from different localities ("Journal Iron and Steel Institute," 1911, II, p. 499).
2. Analysis of material from the chief source of American dolomite ("Mineral Industry," 1905, pp. 47 and 48).
3. Two analyses out of eight different analyses of Indian bauxite. The Madras sample contained the lowest, and the Nagpur sample the highest, alumina in the eight analyses ("Mineral Industry," 1905, pp. 47 and 48).

The bulk of the bauxite used, particularly in the U.S.A., comes from Arkansas, and the analysis of the material, after being washed and calcined, is as follows:—

Mechanical H_2O	0·88 %
Silica	6·40 %
Oxide of iron	1·43 %
Alumina	87·30 %
TiO_2	3·99 %

This material is remarkably high in alumina and produces very fine bricks, which after careful burning can stand a crushing test of 10,000 lbs. per square inch. A brick 9″ × 4½″ × 2½″ weighs 7½ lbs.

When bricks are made for the basic open-hearth furnace they should not contain more than from 6 to 8 per cent. of SiO_2, the white variety of bauxite being used mixed with lime free from silica to form a bond.

An account[1] is given of comparative tests made at the Bethlehem Steel Works with bauxite and magnesite bricks made from different materials, which were placed in the furnace side by side and near to the gas and air ports, and exposed to the highest temperature in the furnace. In 7 minutes the magnesite brick showed signs of melting, while the bauxite brick stood 15 minutes. When both bricks were broken it was seen that the slag had penetrated more deeply the magnesite brick.

The output of bauxite in the U.S.A. in 1911 was 155,618 tons.

Bauxite for linings of furnaces has not, as far as we can learn, been taken up by steel makers.

Alundum.—Alundum is the name given to fused bauxite prepared in the electric furnace. It is stated[2] that it has been used with success in a Héroult furnace at work at Niagara. Alundum is produced in two forms—white and reddish-brown. The white contains less than 1 per cent. of impurities, and the other from 6 to 8 per cent. The fusing-point of bricks produced from the white material is between 2050° and 2100° C. Furnace roofs made with bricks of this class have withstood temperatures which destroy silica bricks in 5 to 6 hours.[3] It is stated, however, that there is some difficulty in using bricks of this material for the roofs of electric furnaces, as the vapours arising from the intensely heated basic slags are injurious to them.

Alundum expands and contracts very slightly.

4. **Chromite.**—This material is an exceedingly refractory neutral substance, consisting chiefly of a double oxide of chromium and iron. As it is not attacked by basic or silicious fluxes, it is most useful in furnaces where chemical action and high temperature are to be resisted.

In 1905 the world's production of chromite was as follows[4] :—

Canada	7,781 metric tons
New Caledonia	51,374 „
New South Wales	53 „
U.S.A.	122 „

It was estimated that in 1907 the world's production was from 90,000 to 100,000 metric tons.[5]

The analyses of chrome ore are given as follows :—

TABLE XXV

PERCENTAGE ANALYSES OF CHROME ORE

No.		Cr_2O_3.	FeO and Fe_2O_3.	Al_2O_3.	MgO.	SiO_2.	CaO.	MnO.	P_2O_5.	H_2O.
1	Turkey	51·7	14·2	14·1	14·3	3·5	1·7	—	—	0·3
2	New Caledonia	55·7	16·6	16·2	9·8	0·25	0·2	0·2	0·05	1·05
3	Bosnia	50–52	39 to 45		Some	2·5	Some	—	—	—

3. Ore used as lining for open-hearth furnace at Diosgyör Works in Hungary ("Journal Iron and Steel Institute," 1890, I, p. 218).

[1] "Mineral Industry," 1905, pp. 48–51.
[2] "Journal Iron and Steel Institute," 1911, II, p. 500.
[3] "Metallurgical and Chemical Engineering," vol. x, pp. 129 and 132.
[4] "Mineral Industry," 1905, p. 74.
[5] "Journal Iron and Steel Institute," 1909, II, p. 545.

As a refractory material, chromite should not contain less than 6 per cent. of silica.

It is stated[1] that chrome ore linings were first used at the Tamaris Works in France, as a neutral lining for the hearth of a Siemens-Martin furnace. Blocks of the ore were built in, the joints being made with mortar composed of two parts of the ore and one part of lime. Three furnaces were in successful use, the sizes being 6, 8, and 12 tons respectively.

When ground, chromite is found useful in basic furnaces along the back walls of both stationary and tilting furnaces, also on the floor of the ports, and as a protection to the silica bricks in the ports. It can be supplied containing from 38 to 42 per cent. of chromic oxide, or with 50 per cent. of chromic oxide.

Chrome Bricks.—These are made from the crushed ore mixed with a suitable binder such as lime, and afterwards pressed into moulds and burned. They are practically infusible, and are used principally in basic open-hearth furnaces in making a neutral course between the fireclay bricks on the bottom plates and the magnesite bricks forming the bottom of the furnace. They are also used in making quick repairs, as they are not affected by sudden changes of temperature.

5. **Limestone.**—As a basic refractory material for lining furnaces, limestone was used successfully at both Witkowitz and Kladno when the basic process was introduced. Wedding[2] gives the analysis of the limestone used as follows:—

Lime	47·46 %
Magnesia	2·93 %
Protoxide of iron (FeO)	3·41 %
Protoxide of manganese (MnO)	0·29 %
Carbonic acid	42·85 %
Silica	2·48 %
Alumina	0·53 %

Dolomite has now come into general use for converter linings, and this material is more durable than limestone and more economical, although limestone is cheaper than dolomite.

Standardising Refractory Materials.—Some effort has been made to classify refractory materials for use in furnaces making iron and steel, but the various qualities of refractory materials going under the same name makes it difficult to find tests which will be simple and practical, and at the same time a sure guide of quality. Mr. Baraduc-Muller[3] suggests that refractory materials should be graded in groups, thus—

1. Aluminium silicate products.
2. Alumina products.
3. Silica products.
4. Magnesia products.
5. Carborundum products.
6. Chromite products.
7. Carbon products.

and that the following values of each should be determined—

1. Chemical composition.
2. Refractory resistance.
3. Absolute and apparent densities.
4. Degree of porosity and calorific conductivity.
5. Mechanical resistance to compression and shock.

[1] "The Engineering and Mining Journal," vol. i, p. 213.
[2] Wedding, "Basic Process," p. 47.
[3] "Revue de Métallurgique Mémoires," vol. vi, pp. 700–729.

These values, he says, would allow of a refractory product being expressed by the following formula :—

$$\text{Value} = \frac{Al_2O_3}{SiO_2 + \text{fluxes}} + \text{cal. resistance} + \frac{\text{absolute density}}{\text{apparent density}} + \text{mech. resistance.}$$

Whether such a formula would be of practical value is somewhat difficult to say, but there is no doubt that a better method is required for the easy testing of refractory materials before use.

Electrodes for Electric Furnaces

The development of the electrode or arc types of electric furnaces, has necessitated considerable investigations into the manufacture and durability of electrodes. Two classes of electrodes are used: (1) amorphous carbon electrodes, and (2) graphite electrodes. The ideal characteristics of an electrode are :—

(*a*) High conductivity.
(*b*) Maximum resistance to oxidation.
(*c*) Freedom from cracking and breaking when subjected to heat.

Originally, amorphous carbon electrodes were used with success in small electric furnaces only, because of the difficulties found in making large sections. Amorphous electrodes are now made at least 20 inches in diameter and 70 inches long, with socket and spigot joints, and used with success in electric steel furnaces. Graphite electrodes are often used, even although more expensive, as they can be easily machined and joined together, possessing also advantages of higher conductivity and greater freedom from cracking and breaking than amorphous carbon electrodes.

The current-carrying capacity of electrodes per square inch of section depends upon several factors, namely—the kind of electrode used, the drop in temperature between the inside of the furnace and the outside end of the electrode, and the length of the electrode. Rules have been devised and constants tabulated, by means of which the size of an electrode for any specific case can be determined.

Amorphous Carbon Electrodes.—The manufacture of carbon electrodes is described very fully in a report by Eugene Haanel, Ph.D., to the Canadian Department of Mines. A carbon electrode factory comprises four essential departments :—

1. Storing and sorting department.
2. Crushing and mixing department.
3. Moulding department.
4. Drying department.

The simplest and cheapest electrodes consist of anthracite, retort coal, and tar, whilst higher quality electrodes have graphite added to the foregoing. The anthracite and retort coal are crushed in ordinary crushers and afterwards in edge runners. When the mixture is ready, tar is added and the whole then treated first in mixers and afterwards in edge runners. The mixture is then allowed to settle for some days, after which it is moulded in a hydraulic press of the extrusion type. After the electrodes are formed they are allowed to settle for at least 24 hours, then dried in the air for about a week. They are then packed into saggars in a drying kiln and baked for 20 to 22 days, the maximum temperature to which they are subjected being about 1410° C. The cost of a complete plant with buildings and all auxiliary machinery designed to give economical working results and capable of producing about 3000 tons of large-size carbon electrodes per annum, costs about £50,000 complete.

Another description[1] given of the manufacture of carbon electrodes states that the materials used consist of coke, hard and soft pitch, coal tar and petroleum oil. Lampblack may be substituted for a portion of the coke where electrodes of superior quality are required. The coke is first crushed and dried in retorts, then ground. The proportion of one mixture used for ordinary electrodes is :—Coke, 325 lbs. ; hard pitch, 110 lbs. ; oil, 1 gallon. The ingredients are mixed for about 20 minutes in steam-jacketed pans, and the mixture at a temperature of about 270° F., is compressed in heavy cast-iron moulds into round plugs about 6 inches thick, by means of hydraulic pressure. The plugs, after cooling to about 200–240° F., are forced through discs from 3 to 5 per cent. larger than the diameter of the finished electrodes. The baking occupies from 10 to 14 days, the temperature being steadily increased to a maximum of 1020° F., after attaining which the furnace is allowed to cool down for 4 to 5 days before being opened. The finished electrodes should have a resistance of about 0·0016 ohm per cubic inch, and be capable of carrying a current of 25 amperes per square inch of cross-section.

Graphite Electrodes.—Probably the best known among graphite electrodes are those made by the Acheson Graphite Co. They are made by subjecting amorphous carbon electrodes in an electric furnace to such a temperature that the elements other than carbon are volatilised, leaving behind the carbon in the graphitic state. A mixture suitable for graphite electrodes is given[2] as—coke, 325 lbs. ; hard pitch, 103 lbs. ; oil, 1 gallon ; iron oxide, 5 lbs. This is prepared as described above, and when formed and baked is ready for treatment in the electric furnace. The following comparison between graphite and carbon electrodes is given by the Acheson Graphite Co. :—

	Acheson-Graphite electrodes.	Non-graphite carbon electrodes.
Specific resistance, ohms per inch cube	0·00032	0·00124
Comparative sectional area for same voltage drop	1	3·8
Weight. Lbs. per cubic inch	0·0574	0·0564
Tensile strength. Lbs. per sq. inch	800–1000	1000–1500
Temp. of oxidation in air	640° C.	500° C.

Although the tensile strength of graphite electrodes is lower than that of carbon electrodes, they are not so brittle. The comparative freedom from cracking of graphite electrodes is obtained by reason of the high temperature to which the electrodes are subjected during their manufacture and the annealing treatment they receive during cooling.

Prices of Electrodes.—The cost of electrodes depends to some extent upon their size and to a large extent upon the distance from the electrode factory to the electric steelworks. In cases where the consumption of electrodes is large and the cost of freight on the electrodes is excessive, it would probably pay to manufacture the requirements at the steel works. It is found more economical to make electrodes at the works of Electrometals Ltd., Welland, Canada, where they manufacture ferro-silicon in the arc type of electric furnace, than to purchase them from other makers. On the other hand, if the consumption of electrodes is small, it would not be profitable to erect an electrode plant. Electrodes suitable for electric steel furnaces cost as follows :—

Carbon electrodes	$1\frac{1}{4}$*d.* to 3*d.* per lb.
Acheson-Graphite electrodes	6*d.* to 9*d.* ,,

[1] "Journal of Industrial and Engineering Chemistry," vol. i, pp. 286–295.
[2] *Ibid.*

SECTION IV

FLUXES

Limestone.—Limestone is used more as a fluxing material, both in the unburnt and burnt states, than as a lining for furnaces. Some prefer it to lime in the basic open-hearth furnace, as there is no lime dust to act on the silica lining and blocks which would tend to fuse the face of the blocks and increase the wear. Limestone is so abundant throughout the world[1] that its price is usually governed by the labour involved in quarrying it and in the cost of its transit to the furnaces. It differs, however, in chemical composition, some deposits consisting almost entirely of carbonate of lime. Chalk for instance, when dried, contains about 99 per cent. of $CaCO_3$. Other deposits, however, contain varying quantities of impurities such as silica, alumina, magnesia, and iron.

The following are some compositions of limestones :—

TABLE XXVI

PERCENTAGE ANALYSES OF LIMESTONES.

	1.	2.			3.
	Sweden.	English—Derbyshire.			Scotch.
	Oaxen limestone.	*a*	*b*	*c*	Harburn.
Lime	53·74	—	—	—	—
Magnesia	0·17	0·75	0·75	—	—
Ferric oxide	0·18				—
Alumina	0·32	6·5	0·95	0·16	—
Calcium carbonate	—	85·66	95·25	99·93	93·92
Phosphoric acid	0·006	—	—	—	0·02
Sulphur	trace	—	—	—	—
Silica	3·14	2·5	1·0	0·6	0·50
Loss on ignition	42·42	—	—	—	—

1. Used at Herräng on account of its high quality. ("Journal Iron and Steel Institute,' 1902, I, p. 51).
2 and 3. Used in cupolas for remelting pig iron and scrap.

Limestone, used as a flux in the blast furnace, requires more coke per ton of ore melted according to the impurity of the limestone. The presence of a large percentage of carbonate of magnesia in the limestone increases the quantity required per ton of iron produced, and, in consequence, the cost is greater.

Limestone is also used as a flux in re-melting pig-iron and scrap for Bessemer and other furnace metal.

Price of Limestone.—Prices vary considerably, but the following figures give a fair idea of the range :—

Britain	2*s.* 0*d.* to 6*s.* 0*d.*	per ton at furnaces.	
America	2*s.* 6*d.* ,, 6*s.* 9*d.*	,,	,,
Germany	2*s.* 1*d.* ,, 4*s.* 0*d.*	,,	,,

[1] The production in 1911 in the U.S.A. alone was 18,203,882 tons, the value of which is given as £1,947,028. "Mineral Industry," 1911, p. 4.

Lime.—Calcined limestone is used extensively in all basic steel processes, and the purer the lime used the more economical are the results obtained in steel making. The presence of silica in excess of 2 per cent. in the lime, increases the amount required of the latter, and the cost of manufacture. The elimination of sulphur is also retarded when silica is present.

Cost of producing Lime.—The following cost[1] is given of the manufacture of lime :—

COST PER 2000 LBS.

	s.	d.		s.	d.
Interest on cost of plant and quarry . .	0	2½	to	0	10
Taxes, minor supplies, etc.	0	5	„	1	0½
Cost of quarrying 2 tons of limestone . .	2	1	„	3	9
Cost of fuel for burning	1	3	„	3	1½
Cost of labour (exclusive of quarrymen) .	1	0½	„	3	4
Total . . .	5	0	„	12	1

These prices are widely different. The lower, it is stated, represents what might be attained by a good modern plant run steadily, and under exceptionally favourable conditions as regards quarrying, fuel, and labour. For an output of 20 tons of burnt lime per day, a kiln 43 feet high and 6 feet in diameter would be required. Different kinds of kilns are used, those in which the fuel is charged in alternate layers with the limestone rock, and those where the fuel is burned in separate fireplaces.

Lime is sold at about 10*s*. per ton.

Fluor Spar.—This material is being used very considerably in steel-making as a flux. It not only produces a more fluid slag, but its principal value is found in the elimination of sulphur in the open-hearth process. It is being used increasingly for steel manufacture and some idea of its importance is obtained from the U.S.A. imports for years ending June 30th, 1910 and 1911[2] :—

1910	16,561 tons,	value £12,650
1911	44,004 „	„ £30,947

A duty of 12*s*. 6*d*. per ton was paid.

In addition to imports, the U.S.A. produced 42,300 tons, the average market selling price of which at Illinois in 1911 was 28*s*. 4*d*. per ton. The grade prices were as follows :—

Gravel	31*s*. 3*d*.	per ton.
Lump	37*s*. 6*d*.	„
Ground	50*s*. to 62*s*. 6*d*.	„

The following table[3] gives the output of fluorspar from the principal countries :—

[1] "Mineral Industry," 1905, p. 429.
[2] *Ibid.*, 1911, p. 269.
[3] *Ibid.*

TABLE XXVII

OUTPUT OF FLUORSPAR IN METRIC TONS

	1910.	1911.
Austria-Hungary . . .	8,000 (*e*)	—
France	8,262	—
Germany	17,988 (*a*)	23,073 (*a*)
Spain	180	—
United Kingdom . . .	62,607	32,100
United States	63,000	42,300 (*e*)

(*a*) Exports. German production is not reported.
(*e*) Estimated.

The composition of fluorspar, as used for steel and iron manufacture, is as follows :—

TABLE XXVIII

PERCENTAGE ANALYSES OF FLUORSPAR

	1.		2.
	English fluorspar.		American.
	a	*b*	
Calcium fluoride	78·4	95·52	83·5 to 93·2
Calcium carbonate . . .	8·1	—	0·25 „ 10·0
Silica	4·2	1·6	0·5 „ 8·0
Alumina	0·5	3·8	—
Oxide of iron	1·0		—
Carbon dioxide	—	1·5	—

1 *a*. "Iron Age," vol. 78, p. 1258.
2. "Mineral Industry," 1911, p. 269.

The price of fluorspar, broken to $1\frac{1}{2}$ inches to 2 inches ring gauge, and delivered at the furnace, varies in this country from 16*s*. to 30*s*. per ton.

SECTION V

FUEL AND ELECTRIC POWER USED IN STEEL MANUFACTURE

Fuels may be classified into four distinct sections: (1) Solids; (2) Liquids; (3) Gaseous (all these are found in nature); and (4) Electrical Energy. A large proportion of the solids are used just as they are found in their native state, namely, wood, peat, and coal. Artificial solid fuels, such as charcoal, coke, and briquettes, are produced from wood, coal, and peat, and find their place in steel manufacture. Liquid fuels are not so abundant in nature nor so well distributed as the solid fuels. They have been used, however, for many years for steel manufacture, particularly in the U.S.A. Gaseous fuels used in steel making are mostly produced from coal, although coke-oven gas is also used, and blast-furnace gases have been experimented with for the same

purpose. Natural gas, found in certain parts of the world (principally in America) is also employed as a fuel for open-hearth furnace work.

Fuels vary in quality. It is sometimes difficult to distinguish between fuels and non-fuels, as so many forms of heat-giving substances find their way into use, some containing many more elements than carbon and hydrogen and their compounds. These elements and compounds, however, supply the principal heat in all fuels when rapidly oxidised by atmospheric air. All kinds of fuel used in steel manufacture can be thoroughly tested to find their heat values, which can be measured accurately. Fuels are generally selected for use according to their calorific value, freedom from sulphur and ash (when solids are used), and also from the point of view of economy. Sulphur in fuel is a very objectionable element, particularly in solid fuels. Liquid fuels and natural gas do not, as a rule, contain so much sulphur as solid fuels.

The World's Coal Production.—Coal deposits are found in most parts of the world, and consist principally of bituminous and anthracite coals, although what is known as brown coal, or lignite, is found in liberal amounts on the continent of Europe and in other parts of the world. The total production of coal for 1910 is given[1] in Table XXIX, with returns for certain countries for 1911.

TABLE XXIX

COAL PRODUCTION OF THE CHIEF COUNTRIES IN THE WORLD, IN METRIC TONS

	1910.	1911.
Asia—		
China	14,591,000	—
India	12,092,416	—
Japan	14,794,208	16,020,000
Australasia—		
New South Wales	8,304,284	8,250,000
New Zealand	2,232,520	2,106,000
Other Australasian Colonies	1,710,930	1,740,030
Europe—		
Austria-Hungary[2]	38,006,840	40,116,743
Belgium	23,127,230	23,112,062
France	38,570,473	—
Germany[2]	221,986,376	234,259,061
Italy	400,000[4]	510,029
Russia	24,572,403	—
Spain[2]	3,550,000	—
Sweden	210,700[4]	—
United Kingdom	264,505,207	268,029,000
North America—		
Western Canada	6,446,336	5,500,000
Eastern ,,	6,564,930	6,602,000
Mexico	2,450,231	—
U.S.A.	445,816,040	455,720,550
South Africa[3]	5,500,219	—
Other countries	7,000,000[4]	—
Total	1,143,739,902	—

[1] "Mineral Industry," 1911, p. 151.
[2] Includes lignite.
[3] Includes Transvaal, Natal, and Cape of Good Hope.
[4] Means estimated.

During the past five years the rate of increase in coal production has been constant in Germany and the U.S.A., namely, 21 per cent., while in the United Kingdom it is only little over 7 per cent. This rapid progress on the part of Germany is consistent with her increase in the output of steel. The following summary shows the amount of coal produced by the three leading industrial countries of the world in the years 1906 and 1911:—

	1906. Metric tons.	1911. Metric tons.	Increase per cent.
U.S.A.	375,397,204	455,720,555	21
United Kingdom	251,050,809	268,029,000	7
Germany	193,533,259	234,259,061	21

In America.—The output in America came from 28 States, three of which—Pennsylvania, Colorado, and New Mexico—produced anthracite coal as well as bituminous coal. From the State of Pennsylvania 80 and 90 million short tons out of 80,389,306 and 90,490,356 short tons of anthracite, were produced respectively in 1910 and 1911. The average cost per ton was 8*s.* 4*d.* in Pennsylvania, and 11*s.* 8*d.* and 12*s.* 6*d.* in Colorado and New Mexico respectively, the values in each case being taken at the mines.

The cost of bituminous coal at the mines varied from 16*s.* 8*d.* in Alaska and Nevada, the highest, to 3*s.* 9½*d.* in West Virginia, the lowest. These were the average prices in 1910 and 1911, except that West Virginia was 3*s.* 9*d.* in 1911. In Table XXX are given the average prices of anthracite and bituminous coal per ton at the mines in the U.S.A. from 1906 to 1911, and it will be observed that the fluctuation in prices has not been very great.

TABLE XXX

AVERAGE PRICES OF COAL AT MINES IN U.S.A.

Kind of coal.	1906.	1908.	1910.	1911.
	s. d.	*s. d.*	*s. d.*	*s. d.*
Anthracite	7 8½	7 11	7 11	8 0½
Bituminous	4 7½	4 8	4 8	4 11

The amount of coke produced in the U.S.A. in 1910 was 36,094,769 short tons, and in 1911 33,349,754 short tons, the average price being 9*s.* 7*d.* and 9*s.* 10½*d.* per ton respectively. The highest price was 23*s.* 4*d.* per ton in the State of Montana, and the lowest 7*s.* 11½*d.* per ton in Virginia.

In Germany.—The three principal coal-mining districts in Prussia are: (1) the Lower Rhine and Westphalian Basin (by far the most important); (2) Silesia, and especially Upper Silesia; (3) the Rhenish district in the neighbourhood of Saarbrucken and Aix-la-Chapelle. The fuel produced in Germany in 1911, in metric tons, was: coal, 160,742,272; lignite, 73,516,789; coke, 25,405,108; coal briquettes, 4,990,988; lignite briquettes, 16,836,679.

Other Countries.—While most other countries of the world have increased their annual outputs during the past five years, the coal production of Sweden, Belgium, and Canada (East) has been approximately the same each year. It is most interesting to trace the development in Japan. In 1874 the output of coal was less than a quarter million tons, and in 1911 over 16,000,000 tons.

The Uses of Coal.—Coal in various grades and qualities is used more or less

in each of the processes as a fuel for preliminary heating, and also as the principal source of heat. In the old shaft furnaces for crucible steel melting, anthracite coal was in common use. Apart from the use of solid and crushed coal for preliminary heating and recarburising purposes respectively, coal in steel manufacture is mostly used as an artificial gas supplied from the many types of gas producers used in connection with open-hearth and crucible furnaces (see Chapter XXXI, on Gas Producers). In Table XXXI are given the analyses[1] of coals from different countries.

TABLE XXXI

ANALYSES OF VARIOUS COALS

No.	Locality or name of coal.	Specific gravity.	C %	H %	O %	N %	S %	Ash %	Percentage of coke left.
1	Welsh. Thomas's Merthyr	1·3	90·12	4·33	2·02	1·00	0·85	1·68	86·53
2	,, Bedwas . .	1·32	80·61	6·01	1·50	1·44	3·50	6·94	71·7
3	Newcastle. Hartly . .	1·29	81·81	5·50	2·58	1·28	1·69	7·14	64·61
4	Derbyshire. Earl Fitzwilliam's, Elsecar	1·296	81·93	4·85	8·58	1·27	0·91	2·46	61·6
5	Lancashire. Ince Hall Co.'s, Arley	1·272	82·61	5·86	7·44	1·76	0·80	1·53	64·0
6	Scotch. Wellwood . .	1·27	81·36	6·28	6·37	1·53	1·57	2·89	59·15
7	Alais. Dep. du Gard .	1·322	89·27	4·85	4·47		—	1·41	—
8	Saint-Girons	1·316	72·94	5·45	17·53		—	4·08	—
9	Königsgrube	1·285	78·39	3·21	17·77		—	0·61	—
10	Sälzer and Neuak, Westphalia	1·288	88·68	3·21	8·11		—	—	—
11	Anthracite. Pennysl-vanian. Pottsville	1·462	90·45	2·43	2·45		—	4·67	—

Calorific Value of Coals.—In Table XXXII (p. 36), the properties of British and foreign fuels are given, showing their particular value as gas-producing coals. It will be observed that the calorific values of the fuels vary from 13,150 B.Th.U. per lb. with very strong coking peas to 7550 B.Th.U. per lb. with the use of lignite nuts and peas.

Coke.—Coke is found more suitable for many of the steel-making processes than coal. In the Huntsman crucible furnace, and in remelting pig iron in the cupola for use in the Bessemer converter, it is always used. It is also used in blast furnaces and in other melting furnaces. Two qualities are produced, as a rule. The soft is of little use in steel and iron melting furnaces, as it is essential to have a dense and hard coke as free from sulphur as possible. In producing coke from coal in one of the many types of coke ovens specially designed for the purpose, the volatile constituents are expelled, leaving a combustible fuel containing usually less sulphur and having a higher calorific value than the coal from which it has been made. Table XXXIII (p. 37)[2] gives the composition of a few typical grades of coke.

[1] Phillips, "Elements of Metallurgy," pp. 51–53.
[2] Percy, "Fuels," p. 417.

TABLE XXXII

PROPERTIES OF BRITISH AND FOREIGN FUELS

No.	Origin of fuel.			Characteristics of fuel.	Size of fuel.	Average analysis of fuel.					Net calorific power.	
	Country.	District.	Locality.			Fixed carbon.	Volatile matter.	Ashes.	Moisture.	Sulphur.	Calories per kilogram.	B.Th.U. per lb.
1	Gt. Britain	Yorkshire	Pearn Valley, Sheepbridge	Coking and swelling	Nuts down to dust	54·8	29·5	6·2	7·8	1·3	6400	11,500
2	Belgium	Mons.	Flenu	Coking. Tendency to clinker	Nuts, peas and fine coal	—	33·0	5·0	—	—	6600	11,900
3	France	St. Etienne	Decize	Very strong coking	Peas	60·0	19·6	13·1	7·3	1·2	7300	13,150
4	Austria	Styria	Fohnsdorf	Peacock coal	Rough coal	48·0	27·0	17·0	10·0	2·2	5000	9,000
5	Bosnia	—	Banjaluka	Lignite	Nuts and peas	11·8	55·3	20·6	15·0	3·8	4200	7,550
6	Germany	Rhenania	Brühl	Briquettes	2″ to 3″	47·3	34·8	4·6	13·3	—	4900	8,800
7	Russia	Polonia	Mine Park	Non-coking	Washed nuts, ½″	48·0	32·0	8·5	11·5	–	5600	10,100

TABLE XXXIII

PERCENTAGE COMPOSITION OF COKE

	1		2		3	
	Actual analysis.	Exclusive of sulphur and ash.	Actual analysis.	Exclusive of sulphur and ash.	Actual analysis.	Exclusive of sulphur and ash.
Carbon	85·84	97·83	91·3	97·33	91·59	97·33
Hydrogen	0·52	0·60	0·33	0·35	0·47	0·50
O and N	1·38	1·57	2·17	2·32	2·05	2·17
S	0·86	—	—	—	—	—
Ash	11·40	—	6·20	—	5·89	—

When ordering coke it is advisable to specify the maximum amount of sulphur, viz. 0·8 per cent. for use in melting iron and scrap steel in cupolas for the Bessemer process, and 0·6 per cent. for crucible furnaces manufacturing high-speed tool steels.

Liquid Fuels.—As compared with fuels of other classes, liquid fuel is not used very much in steel making. It has been applied and is now used in furnaces for the manufacture of crucible steel, in small and large open-hearth furnaces, and in melting iron for the conversion of steel in the Bessemer process. In 1888, James Riley and F. W. Dick secured a patent for the use of liquid fuel in regenerative furnaces, and since then many improvements have been made with the object of utilising oil economically for steel manufacture. Perhaps the chief hindrance to its fuller use is its cost. For instance, in certain parts of the United States, such as Worcester, where the price of coal delivered is from 12*s*. 6*d*. to 16*s*. 8*d*. per ton, it is generally cheaper to use oil, but the fluctuations in the prices of oil, and particularly the increases during 1912, have forced some steel manufacturers to revert to producer gas. Some furnaces are therefore equipped with gas-producing plant as well as fitted with oil jets.

The question of locality determines very largely the cost of oil, as in the case of coal prices. Booth states[1] that oil at Baku costing 3 francs (2*s*. 6*d*) costs 185 francs (£7 8*s*. 6*d*.) in France, making its use prohibitive. The difference of 182 francs is made up of railway and sea carriage, handling, customs, and warehousing. Ninety francs out of the 185 is the cost of duty, so that the same oil at an English port would cost £3 16*s*.

Apart from the question of cost, the use of oil as a fuel in steel manufacture has certain important advantages. It is generally freer from sulphur, does not produce so much dust, and is therefore less troublesome than producer gas in regenerators and flues. For open-hearth furnace practice 40 to 50 gallons of oil are required per ton of steel, and in melting pig iron for Bessemer practice 30 to 40 gallons are required.

The chemical values of petrols found in different parts of the world do not vary much in carbon and hydrogen content. Table XXXIV gives the ultimate composition of the chief available fuels.[2]

[1] Booth, "Liquid Fuels," p. 35.
[2] Lewes, "Liquid and Gaseous Fuels," p. 42.

TABLE XXXIV

PERCENTAGE ANALYSES OF PETROLEUMS

	C	H	O
America	84·9	13·7	1·0
Russia	86·6	12·3	1·1
Borneo	87·8	10·78	1·24
Texas	85·6	11·03	3·51
Caucasus	84·9	13·96	1·25
Burmah	86·4	12·1	1·5

Calorific Value of Petrol.—Comparing the calorific value of petrol with coal, the former is 50 to 60 per cent. higher. The calorific value of good gas coal varies from 5500 to 7000 calories per kilogram. The following table gives the values of liquid fuel oils in different localities :—

TABLE XXXV

CALORIFIC CAPACITY OF LIQUID FUEL OILS [1]

Locality.	Fuel.	Sp. gr. 0° C.	Percentage Analysis.			Calorific capacity.	
			C	H	O	Actual calories.	Calculated calories.
						per kilogram.	per kilogram.
Russian	Pet. refuse	0·928	87·10	11·7	1·2	—	11,018
,,	Astatki	0·900	84·94	13·96	1·2	10,340	11,626
Caucasus	Heavy crude	0·938	86·60	12·30	1·1	11,800	11,200
American	Solid residium	—	97·855	0·489	1·96	8,057	—
Scotch	B. F. oil	0·920	83·64	10·59	9·458	10,328	—

World's Production of Petrol.—The chief oilfields in the world are found in America and Russia. Table XXXVI gives the world's output in metric tons.

TABLE XXXVI

PETROL OF THE WORLD (METRIC TONS) [2]

	1910.	1911.
U.S.A.	28,331,000	29,000,000
Russia	8,952,793	8,290,000
Dutch East Indies	1,700,000	1,590,000
Galacia	1,700,000	1,300,000
Roumania	1,352,300	1,540,000
India	872,000	1,043,000
Mexico	542,400	896,338
Other countries	786,480	1,000,000
Total	44,236,973	44,659,338

[1] Booth, "Liquid Fuel and its Appliances," p. 281.
[2] "Mineral Industry," 1911, p. 557.

Natural Gas.—Natural gas is found in different parts of the world, and from about the year 1884 it has been used in several of the States of America, namely, Pennsylvania, West Virginia, Ohio, and Indiana. It is also abundant in Canada. In 1910 there were 828 producing wells in Ontario, where gas was used for fuel and lighting purposes, and valued at £280,515, or an average of $10\frac{1}{4}d.$ per 1000 c. ft. The output in 1911 was worth £359,220. The gas obtained in Alberta during 1911 was valued at £20,140. On the other hand, there was a fall in the output of petrol from 11,056,337 gallons in 1910 to 10,188,219 gallons in 1911.

The composition of the gas varies in different wells. Dr. Brislee[1] gives the following analysis as an average composition of a number of samples of natural gas occurring in Pennsylvania:—

Methane (marsh gas, CH_4)	67 %
Hydrogen (H_2)	22 %
Ethane (C_2H_6)	5 %
Ethylene (C_2H_4)	1 %
CO	0·6 %
CO_2	0·6 %
N	3·8 %

Several large open-hearth furnaces in Pennsylvania and in Ohio are equipped for the supply of either natural or producer gas. Should the price of natural gas exceed that which makes it profitable to use coal, then producer gas is employed. Steel manufacturers as a rule contract for a considerable period at an economical price, but they find it very convenient to have gas producers attached and ready for use should the gas corporations demand an abnormal price.

The gas is stored in suitable gasometers and conducted direct to the ports of the open-hearth furnace at a pressure of about ½ lb. per sq. inch, instead of being passed through the regenerator chambers, as was customary when first introduced. The gas mixes with the hot air from the regenerators, and burns in the furnace with a shorter flame and is less destructive on the bulkheads of the furnace than producer gas.

In one large works in Cleveland they were paying 7*d.* per 1000 cubic feet in June, 1912, and found it more economical than coal. It was also being used in the large Talbot furnaces at the works of Messrs. Jones & Laughlin at the same period, and doubtless in other works as well.

Cost of Electric Power.—The cost at which electric power can be generated or purchased is a very important factor in the economical production of steel by the electric furnace. Where a good water supply is available and can be harnessed at a moderate cost, is usually to be found the cheapest source of power supply. Unfortunately, water supply cannot always be economically employed for driving electric generators. Further, the districts in which this can be done are often at considerable or prohibitive distances from industrial centres where the power is required, and the cost of transmission is therefore a very important item in the cost of supply. Where a cheap water supply is not available, steam engines or steam turbines, gas or oil engines are employed, the use of one or other depending upon prevailing conditions. Now that blast-furnace and coke-oven gases have been found adaptable for power purposes, many plants are at work which employ these waste gases. Again, low-pressure steam turbines are being found economical for the generation of electricity from exhaust steam, and at works where steam plant is used considerably it often pays

[1] "Industrial Chemistry," p. 159.

TABLE XXXVII

COST OF ELECTRICAL POWER

No.	Locality.	Cost of equipping power plant.	Cost of power.	Selling price or cost price.	Source of power.	Purpose for which power is used.
1	Norway	£7 8s. per k.w. capacity (plant 7500 k.w.)	£ s. d. 2 10 0 per k.w. year	S.P.	Water supply	—
2	,, (Notodden) .	—	1 17 0 ,, ,,	,,	,,	—
3	,, (Jossingfjord)	£6 18s. 8d. to £8 6s. 8d. per k.w. capacity	1 3 8 ,, ,,	C.P.	,,	5-ton Hiorth electric furnace.
4	Italy	—	2 16 3 ,, ,, for consumption of 3000 h.p.	S.P.	,,	—
5	Switzerland (Aare) .	—	0·285d. to 0·38d. per k.w. hour.	,,	,,	2-ton Girod electric furnace.
6	Belgium (Liége) . .	—	0·3d. per k.w. hour	,,	B.F. gas engines.	—
7	North of England . .	—	0·14d. to 0·15d. per k.w. hour	C.P.	Mixed pressure steam turbines.	—
8	North Wales . . .	—	0·29d. per k.w. hour	,,	Steam engines (coal @ 3/6 ton).	—
9	U.S.A. (S. Chicago) .	—	0·25d. ,, ,,	S.P.	Gas engines	15-ton Héroult electric furnace.
10	Niagara.	£30 per k.w. capacity (estimated).	£3 17s. 9d. per k.w. year for consumption of 2000 h.p. or 0·3d. per k.w. hour for consumption of over 5000 k.w. hours per month.	,,	Water supply	—

1 and 2. "Transactions of the Faraday Society," vol. 4, pp. 134–142.
3. "Transactions of the American Electrochemical Society," vol. 18.
4. "Iron Age," vol. 70 (Nov. 20), p. 5.
5. "Electrochemical and Metallurgical Industry," 1908, p. 452.
6. "Journal Iron and Steel Institute," 1908, III, p. 101.
7 and 8. *Ibid.*, 1910, I, p. 110.
9. "Metallurgical and Chemical Engineering," April, 1910.

to collect the exhaust steam from the different units and utilise it for the production of power.

The selection of one prime mover or another must depend, therefore, upon local conditions. Often it is more economical to purchase power from an electricity supply company or corporation than to lay down plant at the works where the power is required.

Table XXXVII (p. 40) gives an idea of the varying costs of electrical power production and cost.

In the cost of production given it must be remembered that the rates of interest and depreciation charged to a power plant by different works vary considerably, also the charge which is made for waste gas, exhaust steam, etc. The cost paid by consumers of power depends also largely upon the circumstances of each case, such as power factor, load factor, continuity or otherwise of load, and amount of current consumed. Special rates are usually quoted by power supply companies to works using considerable amounts, such as for electric furnace working.

The following table gives the equivalent cost in pence per k.w. hour and h.p. hour of power at various rates per k.w. year and h.p. year. It is calculated on the basis of 365 days per year and 24 hours per day. The cost of power per k.w. hour (or h.p. hour) is not necessarily comparable with the equivalent cost of a k.w. year (or h.p. year), and only holds good where the demand for power is practically continuous and steady throughout the year.

TABLE XXXVIII

COST OF ELECTRICAL POWER PER K.W. YEAR AND HOUR, AND PER H.P. YEAR AND HOUR

£ per k.w. year.	£ per h.p. year.	Pence per k.w. hour.	Pence per h.p. hour.
	£ s. d.		
1	0 14 11	0·027	0·020
2	1 9 10	0·055	0·041
3	2 4 9	0·082	0·061
4	2 19 8	0·110	0·082
5	3 14 7	0·137	0·102
6	4 9 6	0·164	0·123
7	5 4 5	0·192	0·143
8	5 19 4	0·219	0·164
9	6 14 3	0·247	0·184
10	7 9 2½	0·274	0·204
11	8 4 1½	0·301	0·225
12	8 19 0½	0·329	0·245
13	9 13 11½	0·356	0·266
14	10 8 10½	0·383	0·286
15	11 3 9½	0·411	0·306
16	11 18 8½	0·438	0·327
17	12 13 7½	0·466	0·347
18	13 8 6½	0·493	0·368
19	14 3 5½	0·520	0·388
20	14 18 5	0·548	0·409
21	15 13 4	0·575	0·429
22	16 8 3	0·603	0·450
23	17 3 2	0·630	0·470
24	17 18 1	0·657	0·491
25	18 13 0	0·685	0·511
26	19 7 11	0·712	0·530
27	20 2 10	0·740	0·551
28	20 17 9	0·767	0·571
29	21 12 8	0·794	0·592
30	22 7 7½	0·822	0·613

SECTION VI

FERRO-ALLOYS

Ferro-alloys are manufactured products of iron in combination with one or more of the following metals: aluminium, calcium, chromium, manganese, molybdenum, nickel, silicon, titanium, tungsten, uranium, vanadium, etc. The manufacture of these alloys has become of considerable importance and magnitude in connection with steel production. In every process of steel manufacture it is usual to employ one or more of the ferro-alloys according to the kind of steel required.

Ferro-metallic alloys perform at least two functions in steel manufacture—

1. In promoting energetic chemical reactions during the removal of the various impurities while acting as deoxidising agents in the different processes of steel manufacture.
2. In giving to the metal from which impurities have been removed, a variety of special physical and chemical properties according to the nature and amount of ferro-alloys added.

Classification of Ferro-Alloys.—Ferro-alloys may be conveniently grouped into two classes, (*a*) common, and (*b*) high-grade alloys, the first being usually employed when making carbon steels, and the second being used for special steels. There are cases, however, where alloys in regular use in the manufacture of carbon steels are employed in making special steels, *i.e.* ferro-manganese, which is invariably used in some degree in ordinary carbon steels, but is also used for manganese steel.

The ferro-alloys commonly used in the first group are: Spiegeleisen, ferro-manganese, ferro-silicon, and ferro-aluminium; and in the second group such alloys as the following: ferro-nickel, ferro-chrome, ferro-tungsten, ferro-titanium, ferro-molybdenum, ferro-uranium, and ferro-vanadium.

The Manufacture of Ferro-Alloys.—Since the introduction of the electric furnace, ferro-alloys containing much higher percentages of the metal or metals alloyed with iron have been produced. Ferro-alloys are now also much freer from foreign and injurious materials which have the tendency to introduce impurities into the steel. The higher percentages of the alloyed metals used as deoxidising agents hasten more rapidly the chemical actions in the steel being manufactured, and absorb less heat in doing so than alloys containing lower percentages of the same metal. Then, again, advantages are found in using alloys containing high instead of low percentages of the metal which it is desired to add to the steel in the form of permanent additions. A smaller quantity of the former is naturally required to produce the same result, and consequently the loss of heat in melting the additions when added in the solid state is minimised. This is often advantageous where it is important to maintain the casting temperature of the steel.

Particulars and Analyses of Ferro-Alloys. Spiegeleisen.—This is a low grade of ferro-manganese containing usually from 10 to 25 per cent. (and sometimes higher) of manganese, with about 5 per cent. of carbon. It is made in several grades, and is used very largely in the manufacture of Bessemer steel. Its introduction for this purpose by Robert Mushet in the year 1856 was of the highest importance in developing the Bessemer process in this and other countries. Ferro-manganese is now being used in conjunction with spiegeleisen for Bessemer and other processes of steel manufacture. In Table XXXIX is given typical analyses of English spiegels.

TABLE XXXIX

PERCENTAGE ANALYSES OF ENGLISH SPIEGELS (DARWYN AND MOSTYN)[1]

Sample.	Mn	C	Si	P	S
1	29·75	5·20	0·65	0·090	Nil
2	20·11	4·99	0·42	0·074	Nil
3	14·40	4·32	0·56	0·063	Nil
4	9·25	3·95	0·44	0·060	Trace

The price of spiegeleisen (20% Mn) averages from £6 to £6 10*s*. per ton.

Silico-Spiegel.—This alloy consists mainly of silicon and manganese in various proportions, and is found useful as a deoxidising agent. The following is an average composition.[2]

Si	C	Mn	S	P	
10·51–14·65	1·0–1·3	19·19–24·48	0·018–0·025	0·12–0·14	per cent.

Ferro-Manganese.—Ferro-manganese, commonly used in steel manufacture, contains about 80 per cent. Mn. Generally, the English material is lower in phosphorus than that obtained from the Continent. It is used in cases where it is undesirable to materially increase the carbon content of the metal (as happens when spiegel is added), and is of great importance in the manufacture of manganese steels. Typical analyses of English ferro-manganese are given below:—

TABLE XL

PERCENTAGE ANALYSES OF ENGLISH FERRO-MANGANESE

Sample.	Mn	C	Si	P	S	Fe
1	60·0	6·4	0·6	0·10	0·005	32·8
2	70·0	6·8	0·7	0·14	0·005	22·3
3	80·0	7·2	0·8	0·18	0·004	11·2

The average price of ferro-manganese (80 per cent. Mn) in 1907 was £15 10*s*. per ton, and in 1908 it dropped to £8 per ton.

Ferro-Silicon.—This was formerly made in the blast furnace as a highly silicated pig containing from 10 to 12 per cent. of silicon. By this method of manufacture, in which much more fuel is used than with ordinary pig iron manufacture, more phosphorus and sulphur are imparted to the alloy, rendering it less effective than ferro-silicon, which is produced by the electric furnace from highly silicious rock, and contains up to 90 to 95 per cent. silicon. The following are percentage analyses of English blast furnace ferro-silicon:—

TABLE XLI

ENGLISH BLAST FURNACE FERRO-SILICON (DARWYN AND MOSTYN)[3]

Sample.	Si	C	Mn	P	S	Fe
1	17·0	0·9	1·5	0·08	0·04	80·4
2	13·45	1·21	1·71	0·058	0·02	83·5
3	11·5	1·5	1·35	0·058	0·03	85·5
4	8·1	1·75	2·2	0·056	0·045	87·8

[1] "Foundry Trade Journal," 1907, p. 424.

[2] "Journal Iron and Steel Institute," 1903, I, p. 630.

[3] "Foundry Trade Journal," 1907, p. 424.

Ferro-silicons made in the electric furnace contain 25–30, 45–50, 75–80, and 90–95 per cent. silicon, of which the following are typical samples:—

TABLE XLII

Percentage Analyses of Ferro-Silicons (Blackwell, Sons & Co.)[1]

Sample.	Si	C	Mn	P	S	Fe
1	32·7	0·27	0·31	0·05	0·04	66·6
2	48·7	0·09	0·13	0·04	0·03	51·0
3	75·8	0·0	0·11	0·02	0·02	24·0
4	94·8	0·0	0·08	0·01	0·02	5·1

The lower percentage alloy (25–30 per cent. Si) is used with advantage in large pieces in the open-hearth and Bessemer processes, without greater loss of silicon than when 10–12 per cent. silicated pig iron is used. It is added to the steel as a rule in the furnace, but sometimes in the ladle before the steel is poured into it. The former practice is the most common. 45–50 per cent. ferro-silicon has a lower fusing point than the 25–30 per cent. alloy, and is, therefore, more energetic in deoxidation, but being less dense it is liable to be held in the slag layer when added to the charge in the furnace.

Ferro-silicons are most useful in the manufacture of silicon steels used for electrical transformers. The price of 50 per cent. ferro-silicon in 1908 was £19 per ton, in 1910 £11 per ton, and in 1912 £12 per ton.

Ferro-Silico-Aluminium.—It is common in most of the processes of steel manufacture to use small percentages of aluminium rather than an alloy of it, such as ferro-silicon and aluminium. This alloy contains about 45 per cent. silicon and 12 to 15 per cent. aluminium, and is employed with the same object as other deoxidising agents. It would appear that for the most part it is used in steel manufactured in the electric furnace to remove oxides in the metal to the slag, producing at the same time very liquid silicates of iron and aluminium, which make the removal of the oxides more rapid and complete. This alloy is also added to the liquid steel in the ladles and shanks before their contents are poured into moulds, thus subduing any "lively" or "rising" tendencies in the steel when cast. It performs the same function as aluminium, but perhaps more effectively.

The following compounds associated more or less with iron are also used in steel manufacture for deoxidising and "physicking" the charges:—

(1) Silico-manganese-aluminium,[2] containing:—

Si 18–20 or 9–11%.
Mn 18–22 or 9–11%.
Al 9–12 or 4·5–6%.

(2) Silico-calcium-aluminium,[3] which has an average composition of:—

Si	50–55%.	Mg . . .	about 0·35%.
Ca	18–22%.	Mn . . .	„ 0·22%.
Fe	12–15%.	S	„ 0·75%.
Al	4–5 %.	P	„ 0·03%.
C	1·0–1·2%.		

[1] "Foundry Trade Journal," 1907, p. 424.
[2] "Société Electro-Metallurgique," Ugine, France. [3] *Ibid.*

The use of this alloy is limited to the manufacture of high quality steels, as it is rather expensive. In addition to its use as a deoxidiser, it is very valuable in assisting desulphurisation of the steel.

The average price of metallic aluminium in 1907 was £190 per ton, but in 1909 the price had been reduced to about £62 10*s*. per ton.

Silico-Manganese.—This alloy[1] is usually made in two compositions, consisting of:—

	Mn	Si	Fe
(*a*)	60–70%.	20–25%.	3–4%.
(*b*)	50–60%.	22–25%.	about 19%.

These alloys are employed as fixed additions in steel manufacture, and are sometimes more conveniently used than the separate alloys, particularly when the Si and Mn in the finished product bear the same proportion to one another as that in the ferro-alloy. Both alloys contain about 0·35 per cent. of carbon, and are very low in sulphur and phosphorus; they are therefore applicable to the manufacture of high-quality steels.

Ferro-Chrome.—This alloy is usually made in the electric furnace, and contains about 60 per cent. of chromium. Chromite (FeO,Cr_2O_3), the ore from which it is made, contains in the pure state approximately 68 per cent. chromic acid. Crude ores containing various percentages of chromic acid are found in Turkey, Caledonia, Canada, India, South Africa, New South Wales, and the U.S.A. The ores from New Caledonia contain about 56 per cent. of Cr_2O_3. The price of the alloy depends upon the cost of the ore. In 1906 the price of ore with 50 per cent. Cr_2O_3 was 70*s*. per ton at an English or continental port. In 1893 it was 110*s*. per ton.

Ferro-chrome is used for imparting to the finished steel special hardening properties, and is a common associate with nickel in steel used for projectiles and armour plates. It is also used in tool and other steels. The following analyses[2] are typical of high and low carbon ferro-chrome alloys made in the Girod electric furnace.

	Cr	Fe	C	Si	Al	Mn	Ca	S	P	
(1)	54·5	22·0	9·5	2·25	0·80	0·15	0·25	0·04	0·03	per cent.
(2)	63·5	35·0	0·6	0·20	0·10	0·10	0·35	0·03	0·02	„

The selling price of ferro-chrome (60 per cent. Cr) varied from £23 to £30 in 1906, and from £18 to £20 in 1911. The price varies with the carbon content, the following prices being paid during 1912:—

	£	*s.*	*d.*
60% ferro-chrome containing 8–10% carbon	16	15	0
60% „ „ 4–6 % „	19	0	0
60% „ „ 2 % max. carbon . . .	48	0	0

Ferro-Tungsten.—Tungsten has been used for over forty years in the manufacture of tool steel. Robert Mushet discovered the self-hardening properties tungsten gave to steel, and for many years no tool steels could be produced to equal Mushet steel. The tungsten tool steels made to-day are almost too numerous to name. Some high-speed steels contain as much as 20–25 per cent. tungsten. Ferro-tungsten is produced from wolframate of iron and manganese, and in the commercial condition contains about 70 per cent. of tungstic acid. Tungsten ore is found in New South Wales, the Argentine, Brazil,

[1] "Société Electro-Metallurgique," Ugine, France. [2] *Ibid.*

China, the U.S.A., Straits Settlements, Spain, Portugal, Britain (Wales and Cornwall), Bohemia, Saxony, etc. The following table[1] gives the composition of ores from various countries :—

TABLE XLIII

PERCENTAGE ANALYSES OF TUNGSTEN ORES

	Spanish.	Australian.	Bohemian (Zinnwald).	United States.
WO_3	64·13	64·23	71·76	63·20
SnO_2	0·68	0·57	—	—
MnO	6·42	1·31	16·30	1·10
FeO	10·88	16·71	7·60	20·36
SiO_2	7·71	3·21	1·69	15·00
Al_2O_3	5·32	2·31	—	—
CaO	1·21	1·21	2·28	—
MgO	3·16	7·16	—	—
CuO	0·38	1·21	—	—
CO_2	—	2·05	—	—
P	—	—	—	trace
S	—	—	—	0·50

Ferro-tungsten is made in the electric furnace, and is difficult to obtain regularly. Chemically prepared tungsten powder is still used very largely, although it is being replaced by the metallic alloy.[2] Ferro-tungsten alloys contain from 50 – 85 per cent. of W. An average analysis is as follows :—[3]

W	C	Si	Mn	Fe	Al	P	S	
72·50	1·75	0·33	0·80	23·39	0·06	0·01	0·01	per cent.

It requires from 140 – 145 units of WO_3 as compared with a theoretical consumption of 120 units, to produce 100 parts of 98 per cent. tungsten. Taking ore at 26*s.* per unit, and the average cost of making tungsten at £90 per ton, the selling price equals $£\frac{26}{20} \times 140 + £90 = £272$. When ore was at 40*s.*, the price was £400 per ton. The price in 1906 was £140, and during 1912 the price has varied from £252 to £300 per ton.

Ferro-Molybdenum.—This alloy is produced from the sulphide of molybdenum (MoS_2), and from wulfrenite (Pb,MoO_4), found principally in Scandinavia, Japan, U.S.A., and Australia. Both minerals are rather scarce, and the production of the ferro-alloy is very small. The pure ore contains :—

	Mo	S	Fe	SiO_2	
(1)	60·0	39·0	0·75	0·4	per cent.
(2)	59·5	39·0	0·90	0·4	„

Ferro-molybdenum is manufactured as powder, and also in the solid metallic state. The powder is made to contain the following[4] :—

Metallic molybdenum		93·39 %
Oxides of Mo	MoO_3	0·70 %
	Mo_3O_8	2·63 %
Iron		1·50 %

[1] "Foundry Trade Journal," 1907.
[2] "Journal, Institute of Mining and Metallurgy," Jan. 18th, 1906.
[3] "Foundry Trade Journal," 1907.
[4] "Journal Iron and Steel Institute," 1911, III, p. 69.

Carbon (total)	0·54 %
Silicon	0·327%
Manganese	0·01 %
Sulphur	0·115%
Moisture	0·22 %

Ferro-molybdenum made by the electric process contains 80 per cent. Mo, 2 to 4 per cent. of carbon, and is practically free from impurities. The average analysis is as follows :—

Mo	Fe	C	Si	Al	Ca	Mn	S	P	
75·0	18·5	4·0	0·2	0·1	0·15	0·15	0·03	0·03	per cent.

It is used considerably in tool-steel manufacture, and in association with one or more metals, such as nickel, chrome, and tungsten ; it is found valuable in steel used for motor cars and in various parts of torpedo boats, submarines, etc. The price of ferro-molybdenum in 1906 was 5*s.* to 6*s.* per lb. of Mo content in the alloy, and in 1912 the average price was about the same figure.

Ferro-Vanadium.—Of recent years vanadium has been found to give peculiarly valuable properties to steels even when added in small percentages. It has been used very largely for high-speed tool steel in association with tungsten, molybdenum, etc. It is prepared from vanadinite or chloro-vanadate of lead represented by the formula $3(Pb_3V_2O_8) + PbCl_2$, and contains about 19·35 per cent. of V_2O_5 in the pure state.[1] The ores actually used for the manufacture of ferro-vanadium contain about 10 per cent. V_2O_5. The ores are found in Spain, Argentine Republic, Mexico, and Sweden, and vary in composition. The following is the analysis[2] of a Spanish vanadium ore :—

V_2O_5	Pb	SiO_2	Fe_2O_3	Al_2O_3	MnO	As_2O_5	P_2O_5	Cu	
12·20	51·27	15·30	10·14	3·15	2·29	1·4	1·10	0·50	per cent.

The ferro-alloy is made with vanadium in proportions varying from 25 to 50 per cent., and carbon varying between 0·3 and 5 per cent. The approximate average analysis of the alloys are as follows :—[3]

	V	Fe	C	Si	Al	Mn	P	S	
50 % quality	55·0	40·0	4·0	0·30	0·10	0·30	0·04	0·03	per cent.
23 to 30 % ,,	34·1	64·22	1·42	0·12	0·12	0·12	0·009	0·03	,,

Ferro-vanadium varies considerably in price, according to the cost of the ore. In 1907 the selling price of the alloy (46 per cent. V) was 10*s.* per lb. of vanadium in the alloy. In June, 1911, the price was 17*s.* 6*d.*, and during 1912 the price varied from 9*s.* to 11*s.* per lb. of vanadium.

Ferro-Titanium.—Ferro-titanium is produced in two grades—high and low, but it would appear that it is difficult to manufacture alloys containing a very high proportion of titanium, owing to the difficulties of fusion on the one hand, and the losses by oxidation on the other hand. For these reasons "The Societé Electro-Metallurgique" have discontinued the manufacture of the high-grade ferro-alloy, making only ferro-titanium containing from 15 to 20 per cent. of titanium.

In the U.S.A. 8000 tons of ore were mined in 1910, which produced 566 tons (1 ton = 2000 lbs.) of concentrates carrying from 75 to 98 per cent. of TiO_2.

[1] "Journal Institute of Mining and Metallurgy," Jan. 18th, 1906.
[2] "Foundry Trade Journal," 1907.
[3] "Societé Electro-Metallurgique," Ugine, France.

Titanium is said by Dr. Léon Guillet [1] to be of interest only from the point of view of the elimination of nitrogen. It has no appreciable influence on the mechanical properties; the tensile strength of steel containing titanium is possibly slightly increased, and the elongation slightly diminished. The elastic limit and resistance to shock are unaltered.

The following are typical analyses of low and high grade ferro-titanium :—

	Ti	C	Si	S	P	Fe (by diff.)	As	Al	Mn	
Low	11·21	0·67	0·37	0·03	0·04	87·68	—	—	—	per cent.
High	51·30	2·82	—	0·047	0·021	44·19	1·12	0·41	0·08	,,

The low-grade alloy is usually sold per lb. of alloy, but the higher-grade alloy is sold per lb. of titanium. The average price during 1912 of ferro-titanium containing 15 per cent. Ti was *6d.* per lb. of alloy. It is used very largely in the U.S.A. in the manufacture of steel for rails.

Ferro-Nickel.—Nickel is produced almost entirely free from iron, and also in the form of a ferro-alloy. It is made from nickeliferous magnetic and copper pyrites, containing very low percentages of nickel, the average being about 5 per cent.

The following are the average analyses of nickel and ferro-nickel :—

TABLE XLIV

AVERAGE PERCENTAGE ANALYSES OF NICKEL AND FERRO-NICKEL [2]

		Ni	C	Si	Al	S	Co	Cu	Fe	Mn	P
1	Nickel, specially pure	99·3	0·09	0·14	0·14	0·01	—	0·07	0·39	—	—
2	,, average sample	97·3	0·14	0·54	0·54	0·02	1·2	0·08	0·49	—	—
3	Ferro-nickel . . .	50·0	0·61	0·10	0·01	0·04	0·01	0·08	48·49	0·28	0·04

1 and 2. Le Nickel Co. 3. Weil and Reinhardt.

Ferro-nickel is also made to contain percentages of nickel as follows :— 25, 35, and 75 per cent., but the nickels almost free from iron, as given in analyses Nos. 1 and 2, are most frequently used in steel manufacture. Nickel is used in various proportions in nickel steels, and with other metals such as chrome, molybdenum, vanadium, tungsten, etc., in tool steels.

The price of nickel in December, 1907, was about £178 per ton, and during 1912 from £165 to £170 per ton.

Ferro-Phosphorus.—This alloy is used to enrich phosphoric slags produced in basic steel furnaces so that they may be made of greater commercial value for agricultural purposes. English-made ferro-phosphorus used for the above purpose contains [3]—

	P	Fe	Si	C	S	Mn	
(1)	24·0	73·3	2·47	0·03	0·08	0·10	per cent.
(2)	17·50	76·12	0·42	0·27	—	5·75	,,

An account is given [4] of the use of ferro-phosphorus which was made in England and used in steel manufacture at the Sharon Steel Co.'s Works, Pa., U.S.A., for black tin plates. It was found that in "pack" rolling of thin plates,

[1] "Journal Iron and Steel Institute," 1906, II, p. 18.
[2] "Foundry Trade Journal," 1907.
[3] "Metallurgie," vol. vi, p. 128.
[4] "Iron Age," May 7th, 1903, pp. 29–30.

the opening of the pack was facilitated by the presence of phosphorus in the steel. It is not stated what percentages of phosphorus were found to give the best results in the material used for this purpose. The analyses of the ferro-phosphorus used were as follows :—

P	Fe	Si	C	Mn	Total
17·23	79·40	1·46	1·14	0·76	99·99 per cent.
25·56	70·66	1·80	1·20	0·64	99·86 ,,

In order to prevent a chilling effect in the charge by the addition of the ferro-phosphorus, experiments were made with phospho-manganese supplied from England having the following analysis :—

Mn	P	Fe	C	Si	Total
65	25	7	2	1	100 per cent.

This composition gave better results.

Ferro-phosphorus is also used to increase the hardness of some basic steels, it being found beneficial in the material when employed for purposes where screw threads have to be cut.

It is rather singular that very good results are obtained from the use of steel containing from 0·1 to 0·15 per cent. of sulphur for the manufacture of bolts and nuts. Better threads are produced and less "dragging" of the material takes place when cutting the threads. It is absolutely essential to have the sulphur present in the form of manganese sulphide to prevent red shortness in rolling.

It is very remarkable that both phosphorus and sulphur should possess such virtues, seeing that their presence in steel for most purposes is injurious.

Miscellaneous Alloys.—Many other alloys are now produced for use in steel manufacture, among others being those set forth in the following table :—

TABLE XLV

PERCENTAGE ANALYSES OF MISCELLANEOUS ALLOYS

No.	Alloy.	C	Si	Mn	P	S	Fe	Ca	Al	Cr	Ni	W	Mo	Mg	Bo
1	Calcium silicide . . .	1·14	69·8	0·22	0·036	0·014	11·15	15·05	2·55	—	—	—	—	0·26	—
2	Silicon chromium . .	3·40	17·17	0·70	—	0·01	28·29	—	—	50·2	—	—	—	0·24	—
3	Chromium molybdenum	0·5	—	—	—	—	—	—	—	30·0	—	—	50·0	—	—
4	Nickel tungsten . . .	0·5 to 1·0	0·25 to 0·50	—	—	—	—	—	—	—	25·0 to 50·0	50·0 to 75·0	—	—	—
5	,, molybdenum .	0·5 to 1·0	0·25 to 0·50	—	—	—	—	—	—	—	25·0 to 50·0	—	60·0 to 70·0	—	—
6	,, chromium . .	1·0	0·25	—	—	—	—	—	—	72·0 to 75·0	24·0	—	—	—	—
7	Ferro-boron	2·855	—	—	0·03	0·005	—	—	—	—	—	—	—	—	32·0

Analyses by G. Watson Gray, F.I.C., Liverpool.

Ferro-sodium is also used, and is generally sold with 25 per cent. metallic sodium and free from lime or an excess of carbon.

We give below, in Table XLVI, average prices at which Ferro-alloys were sold in Britain during 1912.

TABLE XLVI

AVERAGE PRICES OF FERRO-ALLOYS IN BRITAIN, 1912

Ferro-alloy.	Price per lb.	Price per ton.	Scale.
Spiegeleisen (20% Mn)	—	£6 to £6 10*s.*	—
Ferro-manganese (80% Mn)	—	£8 6*s.*	—
Ferro-silicon (50% Si)	—	£12	Basis 45%. 5*s.* 6*d.* per 1% increase or decrease of Si.
Ferro-chrome (60% Cr containing 8–10% Carbon)	—	£16 15*s.*	8*s.* per 1% increase or decrease of Cr.
Ferro-chrome (60% Cr containing 4–6% Carbon)	—	£19	10*s.* per 1% increase or decrease of Cr.
Ferro-chrome (60% Cr containing 2% max. Carbon)	—	£48	20*s.* per 1% increase or decrease of Cr.
Ferro-tungsten	2*s.* 3*d.* to 2*s.* 8*d.* per lb. of W.	—	—
Ferro-molybdenum	5*s.* 6*d.* per lb. of Mo.	—	—
Ferro-vanadium	9*s.* to 11*s.* per lb. of V.	—	—
Ferro-titanium (15% Ti)	6*d.* per lb. of alloy.	—	—
Calcium silicide	—	£40	—

PART I

THE CRUCIBLE PROCESS

CHAPTER III

CRUCIBLE STEEL MANUFACTURE

Historical.—The crucible process is the oldest of the four leading present-day methods of steel manufacture and held the supreme position in the steel-making industry for over one hundred years, until Bessemer brought his converter process before the notice of the world. To this day the crucible process still occupies the premier position in the manufacture of the highest qualities of steel.

Since the year 1740, when Benjamin Huntsman introduced crucible steel manufacture into Sheffield, many modifications in the mixtures used and methods adopted, have been brought out from time to time.[1]

Huntsman's original method of melting blister or other highly carbonised steel is the one still adopted in Sheffield for the manufacture of high carbon steel, together with the modifications introduced by Mushet, Heath, and Vickers, of melting iron with charcoal and manganese.

In America, the prevailing method is to carbonise the charge to the percentage required, by the introduction of charcoal, the carbon from which being rapidly absorbed by the bar iron when the latter is melted.

For the production of crucible steel castings, the "pig and scrap" method is employed, the materials being mixed in such proportions as will give the desired carbon percentage to the resulting steel.

The "pig and ore" method has also been tried, in which the pig iron in small pieces is melted together with iron ore. This does not appear to have been adopted to any large extent in crucible steel manufacture.

In all the above methods the metal was, at one time, tranquillised or "killed" by keeping it in a molten condition for a sufficiently long time to ensure sound ingots. With a view to shortening the process, Mitis brought out his method of "killing" the molten metal by adding to it a small quantity of ferro-aluminium or aluminium immediately after fusion, the metal being ready for pouring a few minutes later.

Several other methods have been suggested and tried from time to time, but all have been more or less a combination or variation of the preceding methods.

With a view to adopting the crucible process for the manufacture of high quality steel from cheap materials, basic crucibles have been tried, but they do not appear to have met with success.

[1] See paper read by Mr. (now Sir Robert) Hadfield before the Iron and Steel Institute in 1894.

General Remarks.—The advent of electric furnaces has arrested, in some degree, the development of the crucible steel process, but not, it would appear, to the extent looked for by the advocates of the electric furnace. One of the chief hindrances in the progress of the electric furnace is the cost of electric power required in the process, and it is therefore in the manufacture of higher grades of steel such as are made by the crucible process, where most is expected from the electric furnace. There is no question about the quality of steel that can be produced in this latest type of furnace, but the name "crucible" has been associated so long with what stands for the very best qualities of steel, that some users will have no other, believing that other steels must necessarily be inferior.

Another rival to the crucible process is the small surface-blown Bessemer converter, which is being used increasingly for the manufacture of high quality steel for small and intricate castings hitherto made by the crucible process only. It is found that when pig iron and scrap containing low percentages of sulphur and phosphorus are used, a very good quality of steel can be produced at a temperature almost equal to that obtained in the crucible furnace and as suitable for the purpose required, as well as at a considerably lower cost.

The use of what is known as the "baby" type of open-hearth Siemens furnace is also being advocated as a substitute for the crucible process in producing steel for castings such as are being made by the small Bessemer converters. From the reports of results obtained from this furnace, it appears that the crucible furnace has also a formidable rival in the small open-hearth furnace for the manufacture of high quality steel castings.

Manufacture of Crucible Steel.—For the manufacture of tool steel which varies in carbon percentage from 0·5 per cent. to 1·5 per cent. according to the temper of the steel required, the materials used must be carefully selected and proportioned. (See Chapter XI for typical analyses of materials, proportions used, and qualities of finished steels.) One method in common use is to select blister steel (the product of the cementation converting furnace) of such grade as will give the required temper, and simply melt it in the crucible. This, as has been already stated, was Huntsman's original method, and by it, good homogeneous steel can be produced. An alternative method is to melt blister steel of somewhat higher carbon content than is required in the resulting steel, and reduce it to the desired carbon content by the addition of Swedish bar iron. A common method now adopted, however, is to melt Swedish bar iron and raise the carbon percentage as required by the addition of charcoal. This method may be reversed by melting pieces of very pure pig iron and lowering the carbon percentage by means of Swedish bar iron.

Bessemer steel and open-hearth steel have not been without their uses in the crucible process, since large quantities of tool steel have been produced by melting these steels in the crucible.

High-speed steel in its various grades and qualities is also the product of the crucible process, the required analysis being obtained by the addition of ferro-alloys, such as ferro-vanadium, ferro-tungsten, ferro-chrome, ferro-molybdenum, ferro-titanium, etc.

Chemical Reactions in the Crucible.—Although the crucible process is practically one of melting only, it is important to notice that some chemical actions and reactions take place during the operation. The chief objection, as stated elsewhere, to the use of plumbago crucibles, is that the charge takes up a considerable amount of carbon from the crucible; moreover, whether plumbago or clay crucibles are used, silicon is taken up by the charge from the crucible, making it difficult to obtain a low silicon steel unless pure materials, low in silicon, are used. It should be noted that the silicon is taken up during the

"killing" period, as by means of the silicon, the homogeneity of the steel is greatly increased.

By the Mitis method of "killing," which involves the addition of Aluminium, the period ordinarily occupied by this portion of the process is to a large extent eliminated, and although as a result a small percentage of aluminium is added to the steel, this is not objectionable provided it is kept down to about ·03 per cent. The possibility of silicon being absorbed by the steel from the crucible is therefore lessened.

Some idea of the loss involved in adding aluminium to the molten steel for "killing" purposes may be obtained from the following:—

Material melted.	Aluminium added.	Aluminium in steel produced.
Bessemer spring scrap	0·10%	0·076%
Open-hearth boiler plate scrap .	0·10%	0·068%

Both sulphur and phosphorus tend to increase slightly in percentage during the process, due to loss in melting. In coke-fired furnaces, the increase in sulphur from the coke is quite noticeable. The change in chemical composition which takes place in the crucible process is clearly seen from the typical case given below, in which 40 lbs. of open-hearth acid boiler-plate scrap were melted in a clay crucible in a coke-fired furnace:—

Silicon increased . . .	from	0·02%	to 0·11%
Manganese decreased . .	„	0·54%	to 0·29%
Sulphur increased . . .	„	0·05%	to 0·09%
Phosphorus remained constant at		0·06%	

It will be observed that the increase in silicon and sulphur was considerable, while the manganese was reduced by oxidisation, and the phosphorus unaffected.

CHAPTER IV

THE EVOLUTION OF THE CRUCIBLE FURNACE

Improvements in crucible steel furnaces have been confined within narrow limits, due perhaps to the nature of the process, which is principally the melting of materials in a closed vessel by the application of external heat, passed through the walls of the crucible before it reaches the materials to be melted. The scope for improving the design of furnaces has chiefly lain in the direction of increasing the rate of melting and in reducing the rate of fuel consumption, although considerable attention has been given to methods of working and to means for prolonging the life of furnaces.

There is unquestionable evidence from the Patent Office records that much time and talent have been expended in seeking to perfect this process.

The original furnace employed by Huntsman in 1740 was heated with coke. Since then other fuels, such as coal, gas, and oil, have been employed, and it has become common to classify crucible furnaces according to the fuels used.

The use of air, both heated and under pressure, has been introduced in various forms of furnaces to assist in the complete combustion of the fuels. A brief outline of the principal improvements is given in the following pages.

Earliest Use of Crucibles.—While it is admitted that Huntsman was the first to melt steel in crucibles, Professor Henry Louis[1] refers to the fact that crucibles were used in the fourteenth century for the manufacture of brass. This was mentioned in "Aula Subterranea" by Lazarus Ercker in 1574. Moreover, what is known as "Wootz" steel was reduced directly from hematite and magnetite ores in small fireclay crucibles in India 2000 years ago.[2]

Huntsman Furnace.—Fig. 1 shows a sectional elevation of the early type of coke-fired crucible furnace—still so much used in its improved form shown in Fig. 2, in the district where Huntsman first melted steel—and while many other processes have been introduced for making steel in larger quantities than can be made in the crucible furnace, Huntsman's coke-fired furnace retains a prominent place for the manufacture of high quality tool steels. Cheaper methods of producing crucible steel have come into use chiefly because of a fuller knowledge of the materials employed. The Huntsman furnace is also used in small foundries in this and other countries for the production of steel for castings, also for melting other metals.

In perfecting his process, Huntsman found more difficulty in obtaining a suitable fire-resisting clay for the crucible, than in the design of the furnace itself or in the application of the fuels then available. Troubles arose with the fuels from an imperfect knowledge of the laws of combustion. The Huntsman furnace is more fully described in Chapter VI.

[1] Paper read before the University of Durham Phil. Soc., Feb. 9, 1911.
[2] Stahl und Eisen, vol. xxi, p. 209.

Coke-fired Furnace utilising Waste Heat.—As far as can be traced, the first important improvement in the design of crucible furnaces was made by

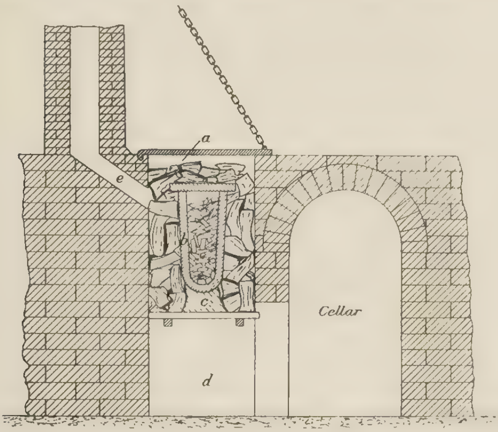


FIG. 1.—Huntsman Coke-fired Crucible Furnace; Original Type.

a, Melting-hole; *b*, Crucible; *c*, Fireclay-block; *d*, Ashpit; *e*, Chimney-flue.

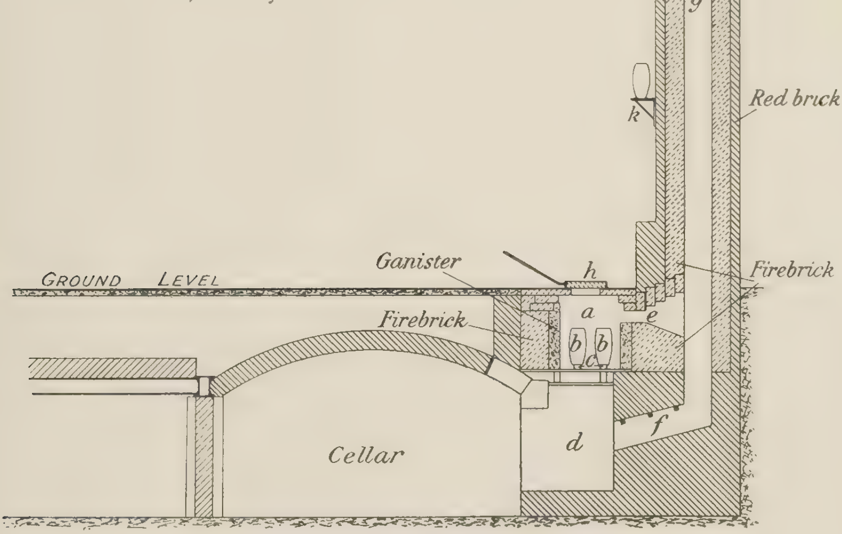


FIG. 2.—Huntsman Coke-fired Crucible Furnace; Modern Type.

a, Melting-hole; *b*, *b*, Crucibles; *c*, Fireclay stands; *d*, Ashpit; *e*, Chimney-flue; *f*, Auxiliary chimney-flue; *g*, Chimney; *h*, Melting hole cover; *k*, Shelf for drying crucibles.

Johnson in 1853. Fig. 3 is a sectional drawing of the furnace patented by him. In this furnace he provided for the utilisation of the waste gases for heating the air of combustion, and also for a supply of air under pressure to the furnace through the grate chamber. These two objects have been included in different forms in many furnaces since then.

Multiple-Crucible Furnace.—In 1855 Henry Bessemer patented a crucible furnace having a series of melting holes around a conical stack, in the walls of which the furnace flues were made. Each crucible had a stopper in the bottom, through which the metal was tapped and carried direct to the mould, placed in the centre of the stack below the melting holes.

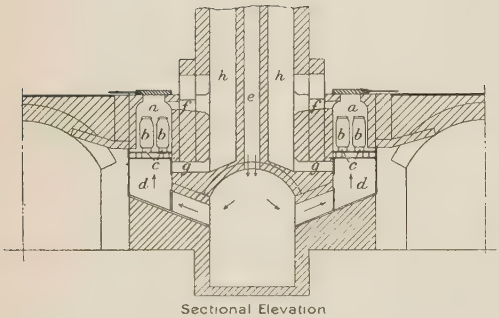


FIG. 3.—Coke-fired Crucible Furnace, for Utilising waste Heat for heating Air of Combustion.

a, *a*, Melting holes; *b*, *b*, Crucibles; *c*, *c*, Fireclay stands; *d*, *d*, Grate chambers; *e*, Flue for supplying Air for Combustion; *f* and *g*, Chimney-flues; *h*, *h*, Chimneys.

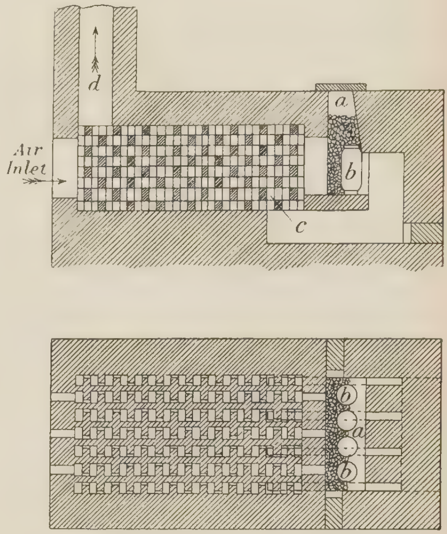


FIG. 4.—Siemens' Regenerative Crucible Furnace; First Design.

a, Melting hole; *b*, Crucible; *c*, Regenerators; *d*, Chimney.

Siemens' Regenerative Crucible Furnace.—In 1856 F. Siemens patented regenerators for use in the crucible furnace. The chequered brickwork chamber which was improved in 1857 by himself and his brother, C. W. Siemens, has long since become an institution in the design of open-hearth and other furnaces, and was adopted to utilise the waste gases for heating the air required for the combustion of the gases from the fuel. Fig. 4 shows a sectional drawing of the crucible furnace and regenerator combined, in which coke is shown as the fuel around the crucible.

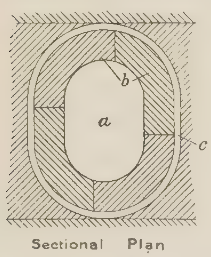


FIG. 5.—Inner Lining for Crucible Furnace Melt-Hole.

a, Melting hole; *b*, Special ganister stone lining; *c*, Filling of coke dust or other bad conductor of heat.

Improved Linings for Crucible Furnaces.—With the object of reducing the cost of repairs to melting holes, Samuel Fox, in 1860, patented a simple form of inner lining, shown in Fig. 5, to preserve the main body of the furnace. The lining was built up in sections of ganister stone, and between the lining and furnace body a filling of coke dust or other bad conductor of heat was inserted. These linings could be renewed without interfering with the main structure of the furnace.

Combined Cupola and Crucible Process.—In 1863 a duplex method of melting first in the cupola, and finishing in the crucible, was patented by G. Davies. There are no records as to whether it was actually

tried, but recent progress in the combined use of the Bessemer converter and the Siemens furnace for producing steel rapidly, finds a certain harmony of principle in Davies' patent, which had for its object the rapid production of crucible steel.

Tilting Crucible Furnace.—The suggestion to use a tilting furnace appears to have been made first by T. Rochussen, who, in 1864, provisionally patented a furnace with this object. He did not, however, complete his patent, and the subject was afterwards taken up by others. The principle of tilting "air-blown" furnaces was introduced by Henry Bessemer some years before this date.

Siemens' Gas-fired Crucible Furnace.—In the sectional elevation of crucible furnace shown in Fig. 6, are embodied many of the features found in the modern

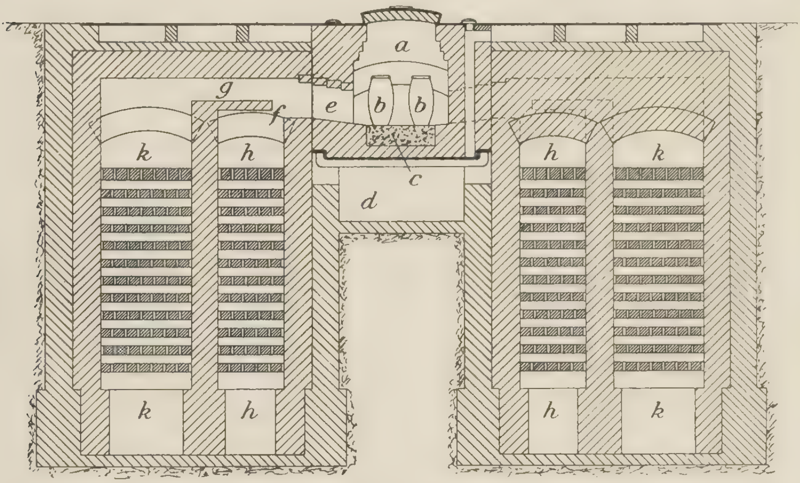


FIG. 6.—Siemens' Gas-fired Crucible Furnace.

a, Melting hole; *b*, *b*, Crucibles; *c*, Coke bed; *d*, Vault; *e*, Combustion chamber; *f*, Gas port; *g*, Air port; *h*, *h*, Gas regenerators; *k*, *k*, Air regenerators.

gas-fired furnace, although it is as long ago as 1866 since C. W. Siemens patented the furnace illustrated. The crucibles are placed in two or more rows in the melting chamber, which is built independently of the regenerators, the latter being placed at the sides. The structure is kept cool by the vault and passages below the melting chamber. The air ports are arranged above the gas ports, and the mixing can be accelerated by contracting the gas openings from the regenerators and by giving them an upward direction. The crucibles are placed opposite or between the gas ports, and rest upon a coke-dust hearth.

Liquid Fuel Crucible Furnace.—Fig. 7 shows sectional elevations of the Nobel furnace which was patented in 1884. It was among the first steel-melting crucible furnaces of the oil-fired type used in America. Three chambers are shown: the one nearest the oil supply is used for melting, the second for heating the charged crucibles, which are afterwards removed to the first chamber, whilst the third compartment is used for examining the flame. Two crucibles are placed in each of the melting and heating chambers. The fuel is supplied from an oil tank and passes through pipes into the oil pans. The air is admitted between the pans, and through an opening in the top, which is regulated by means of a cover. Heats are very rapidly obtained from this furnace, but the

brickwork lining suffers in consequence, having to be renewed every two to three weeks.

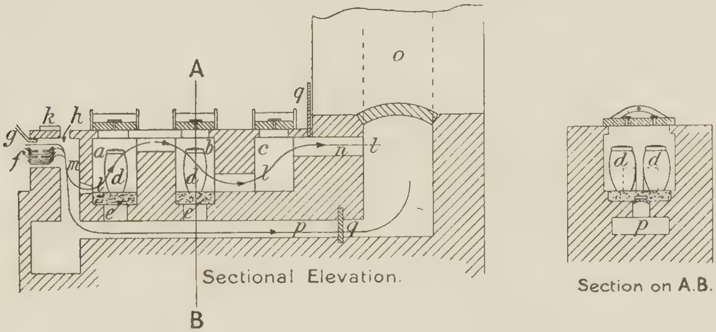


Fig. 7.—Nobel Liquid Fuel Crucible Furnace.

a, Melting chamber; *b*, Heating chamber; *c*, Examination chamber; *d*, *d*, Crucibles; *e*, *e*, Coke beds; *f*, Oil pans; *g*, Oil supply pipe; *h*, Air inlet; *k*, Air regulating cover; *l*, *l*, *l*, Direction of gases through furnace; *m*, Combustion chamber; *n*, Outlet flue; *o*, Chimney; *p*, Byepass flue; *q*, *q*, Dampers.

In 1885, T. Nordenfelt patented an oil jet for use in the Nobel furnace, Fig. 8 showing the arrangement, which was designed for burning naphtha or other volatile liquids. Through the central jet the oil is forced against a plate, which breaks up the stream of oil and causes a fountain-like spray on either side of the plate. Heated air, issuing through pipes on either side of the oil jet, mixes with the oil spray and produces a highly combustible mixture of gases.

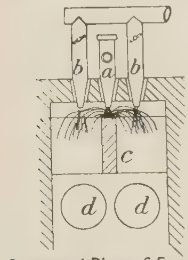


Fig. 8.—Nordenfelt Oil Jet for Nobel Crucible Furnace.

a, Oil jet; *bb*, Air jets; *c*, Dividing wall; *d*, *d*, Crucibles.

Modern Oil-fired Crucible Furnaces.—Fig. 9 shows the crucible furnace which has superseded the Nobel furnace in America. It is simpler in design, and holds 6 to 8 crucibles in the melting chamber. The maximum life of the furnace is about two weeks, after which the side walls and arches of the melting chambers have to be rebuilt. The bottom of the furnace on which the crucibles rest is made of coke and crushed crucible pots.

As an improvement on the furnace illustrated in Fig. 9, which is still used in the Milwaukee district, Carl Smerling[1] describes a furnace in which oil jets are used instead of pans (see Fig. 10). The oil is supplied to the burner under a pressure of 10 to 20 lbs. per square inch, while the air used is at a pressure of 20 to 40 lbs. per square inch. By using heavy refuse oil weighing 7 to 8½ lbs. per gallon, satisfactory results were obtained. Low-pressure burners which atomise 15 to 30 gallons of oil per hour, are not suitable for this furnace, as the spray is said to damage the crucibles.

A new form of regenerative oil furnace,[2] in which 16 crucibles containing an average charge of 85 lbs. are heated at one time, is shown in Fig. 11. Six heats each of 12 crucibles are obtained in 16 hours, the first heat taking 4 hours to melt, and each of the others about 2¼ hours. Seventy-two pots in all yield 6120 lbs. of steel per day. To melt each short ton of steel, 160 gallons of fuel oil are required, or 30 gallons of oil per hour. The oil used weighs 7·3 lbs. per gallon, and its composition is given as: Carbon, 86 per cent.; Hydrogen,

[1] "The Foundry," vol. 36, p. 167. [2] "The Foundry," vol. 37, p. 61.

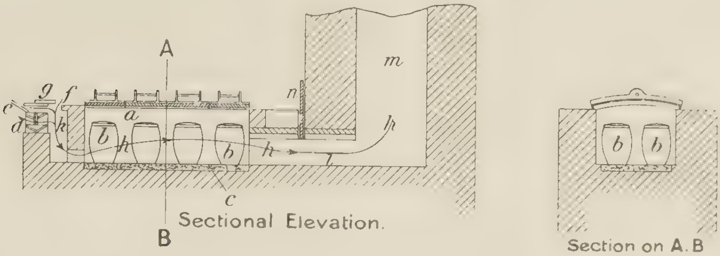


FIG. 9.—Improved Type of Nobel Liquid Fuel Crucible Furnace.

a, Melting chamber; *b*, *b*, Crucibles; *c*, Coke bed; *d*, Oil pans; *e*, Oil supply pipe; *f*, Air inlet; *g*, Air regulating cover; *h*, *h*, *h*, Direction of gases through furnace; *k*, Combustion chamber; *l*, Outlet flue; *m*, Chimney; *n*, Damper.

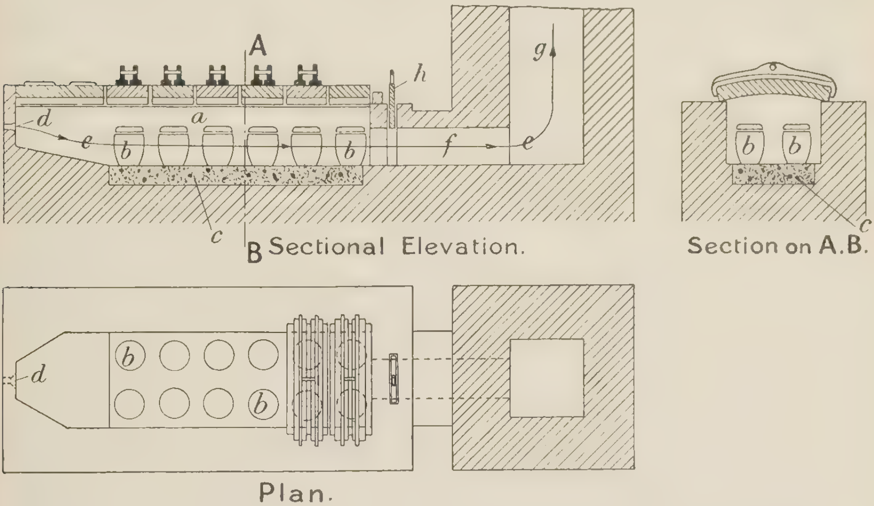


FIG. 10.—Improved Liquid Fuel Crucible Furnace.

a, Melting chamber; *b*, *b*, Crucibles; *c*, Coke bed; *d*, Inlet for oil jet; *e*, Direction of gases through furnace; *f*, Outlet flue; *g*, Chimney; *h*, Damper.

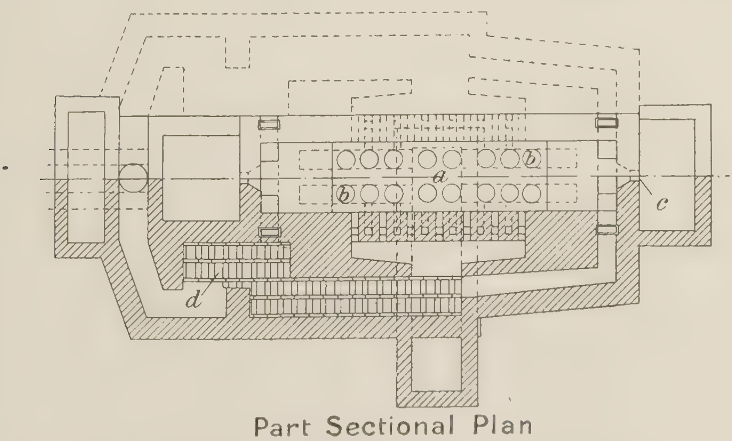


FIG. 11.—Oil-fired Crucible Furnace with Regenerators.

a, Melting-chamber; *b*, *b*, Crucibles; *c*, Inlet for oil jet; *d*, Regenerators.

12·06 per cent.; Oxygen, 1·34 per cent.; Sulphur, 0·6 per cent. To burn 30 gallons of oil per hour, 48,620 cubic feet of air are required, and by means of the regenerator chambers the air is delivered at a temperature of 2190° F.

Application of Water Gas to Crucible Furnaces.—In 1890 Samuel Fox patented an arrangement whereby a jet of water gas was introduced to mix with the hot air ascending from the regenerators, thus accelerating the combustion of the gas and air in their passage from the regenerators to the crucible melting holes, and intensifying the heat.

Economy in the Repair of Furnaces.—To reduce the cost of lining ordinary Huntsman crucible furnaces, W. Kirkham, in 1896, patented a crucible furnace in which the lining was encased in an iron frame and rested upon special fire-grate bars. Between the outer structure and the iron frame an annular space was left to allow a free passage of air to keep the frame cool. By this means a spare lining could be introduced as required, avoiding the serious delay which takes place every four or five weeks with the ordinary furnace, due to the relining of the walls with ganister and the rebricking of the top of the melting hole. Fig. 12 shows a section of the furnace, with the special casing containing the lining in position.

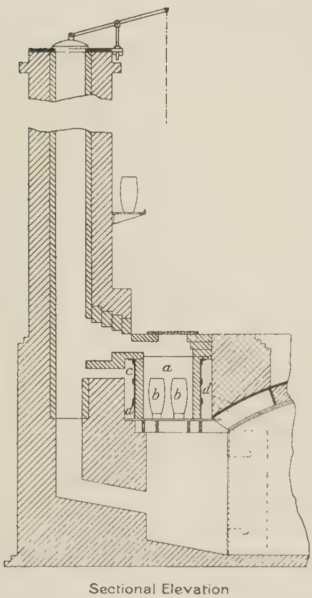


FIG. 12.—Renewable Inner Lining for Coke-fired Crucible Furnace.

a, Melting hole; *b*, *b*, Crucibles; *c*, Iron frame containing renewable lining; *d*, *d*, Air passage round frame.

Dawson, Robinson and Pope Gas-fired Furnace.—Dawson, Robinson and Pope designed a furnace in which each melting hole was kept under control by means of valves or dampers near to the melting chamber (see Fig. 13). Two pairs of air and gas regenerators supplied heated air and gas to the melting holes through independent gas and air ports and passages for each melting hole. In this way the temperature of each melting hole was more easily controlled. This furnace, which is more fully described in Chapter VIII, was patented in 1897, and has been very successful in reducing the amount of fuel consumed in comparison with the ordinary coke-fired furnace.

Appliance for removing Crucibles from Furnaces.—To remove the crucible at a white heat from the melting hole by hand tongs is perhaps the most trying operation in steel making. It is necessary for the man to stand over the top of the furnace and raise the charged crucible while he is exposed to intense heat. To avoid having this operation performed by hand, J. M. Gledhill patented, in 1898, a furnace with movable bottom, upon which the crucibles rested, and when the charge was melted the crucibles were raised to the floor-level, making it easier for men to carry all the crucibles away and accelerating the distribution of steel to the various moulds. Fig. 14 shows the device employed for raising the movable bottom of the furnace. The overhead shaft was extended over a series of melting holes, but each furnace could be operated independently by means of a clutch gear, the loose tops on the furnace being lifted simultaneously with the bottom.

Improvements in Portable Furnaces.—Many designs of portable furnaces have been made to reduce the expenditure in crucibles, in melting the charges

rapidly, and in conveniently transferring the furnace to any part of the steel

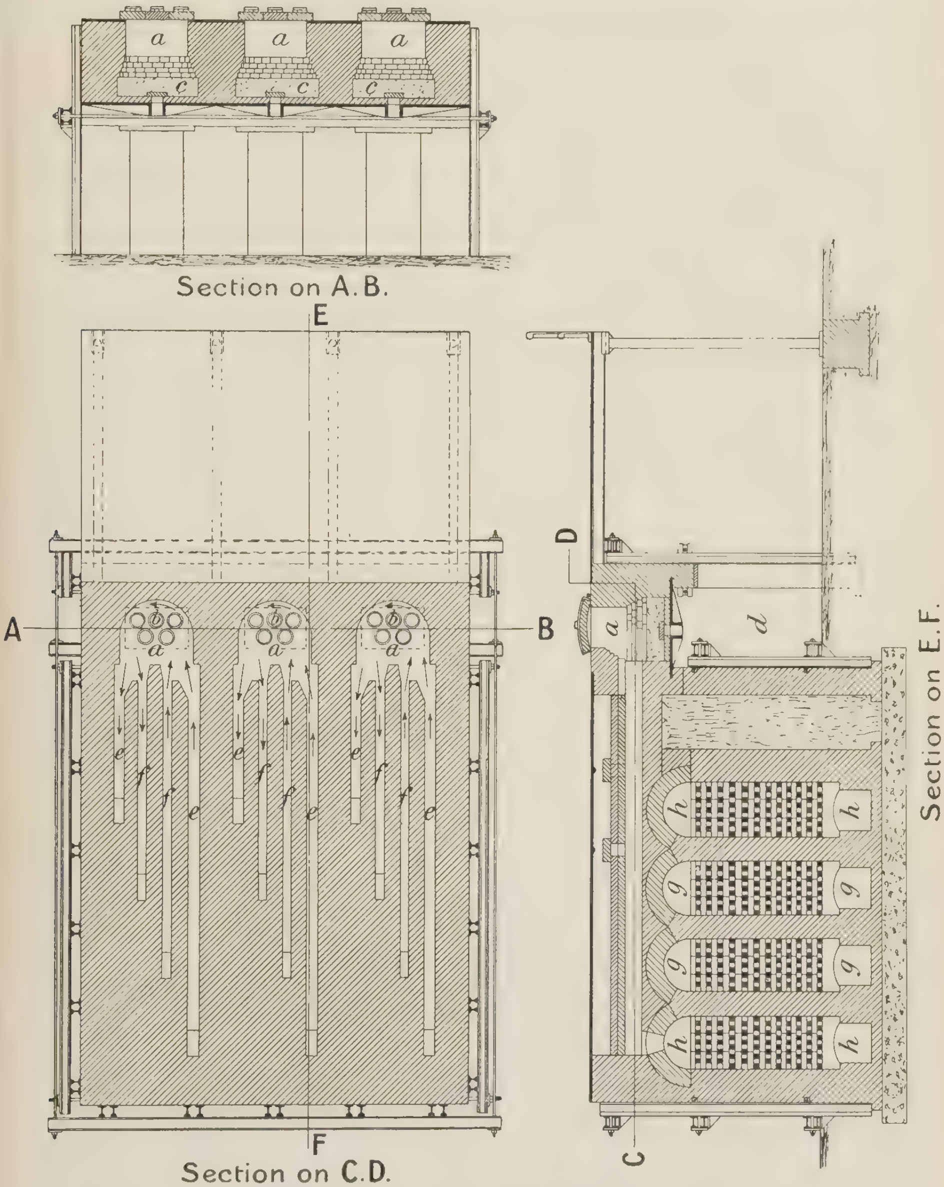


FIG. 13.—Dawson, Robinson, and Pope Gas-fired Crucible Furnace.

a, *a*, Melting holes ; *b*, *b*, *b*, Crucibles ; *c*, *c*, *c*, Coke beds ; *d*, Vault ; *e*, *e*, Air flues ; *f*, *f*, Gas flues ; *g*, *g*, Gas regenerators ; *h*, *h*, Air regenerators.

foundry. Fig. 15 shows a typical tilting furnace patented by Harvey in 1903, and subsequently improved in 1906. It is mounted upon a frame fitted with

wheels, which can be moved on rails. The charge can be tipped from the crucible without removing the latter from the furnace.

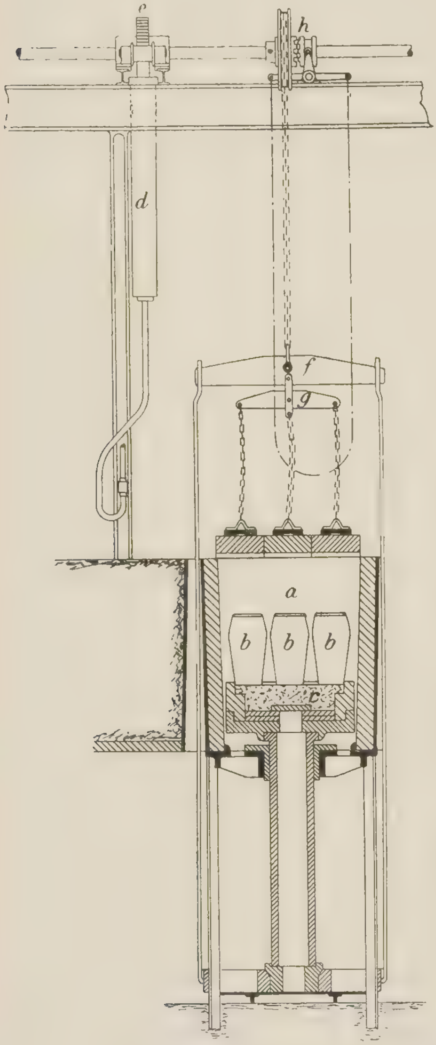


FIG. 14.—Appliance for removing Crucibles from Furnaces.

a, Melting hole; *b*, *b*, *b*, Crucibles; *c*, Coke bed; *d*, Hydraulic cylinder; *e*, Ram for operating chain-wheel shaft; *f*, Crossbar for lifting movable bottom; *g*, Crossbar for lifting covers; *h*, Clutch.

Improved Design of Liquid Fuel Furnace.—Fig. 16 is an illustration of a furnace patented by N. K. Peace in 1904. The special feature in this design, apart from the use of liquid fuel, is the means adopted for concentrating the heat around the crucibles. The refractory bed on which the crucibles rest is perforated so that the flame may pass through and surround it. The admission of air and oil takes place at the bottom and on one side of the furnace, and is directed in a path tangential to the floor of the furnace.

Regenerative Crucible Furnace with Double-chambered Melting Holes.—R. H. Radford patented, in 1906, an improvement in the ordinary gas-fired regenerative crucible furnace. In Fig. 17, which gives a sectional elevation of the furnace, it will be observed that the crucibles are placed on each side of a dividing wall. When the gas and air from the regenerators on one side have spent themselves around the crucibles in one chamber, they pass over the dividing partition and around the crucibles in the second chamber on their way to the regenerators and the chimney. As the direction of the gases is reversed every twenty minutes, the crucibles in each chamber get the flame on the bottom and top alternately. A secondary supply of gas and air can be delivered from the mid partition wall if desired.

Crucible Furnaces with Forced Draught.—The application of forced draught to crucible furnaces in one form or another has been the subject of numerous patents since 1853, when Johnson embodied this feature in his patent. The direction of the blast, its temperature, pressure, and volume, are important factors in the successful melting of steel in crucibles. These considerations have had the attention of inventors.

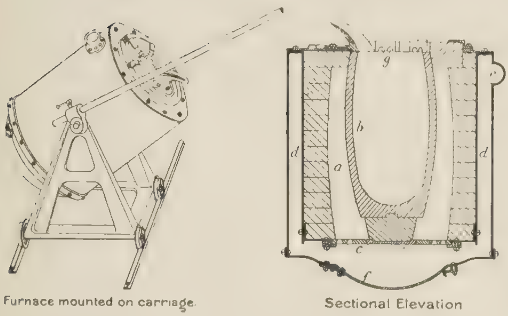


FIG. 15.—Portable Crucible Furnace.

a, Melting hole; *b*, Crucible; *c*, Grate grid; *d*, Annular air chamber; *e*, Air inlet; *f*, Drop bottom for removal of ashes; *g*, Outlets for waste gases.

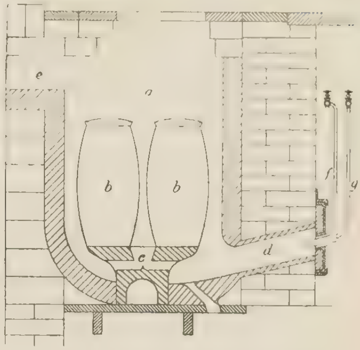
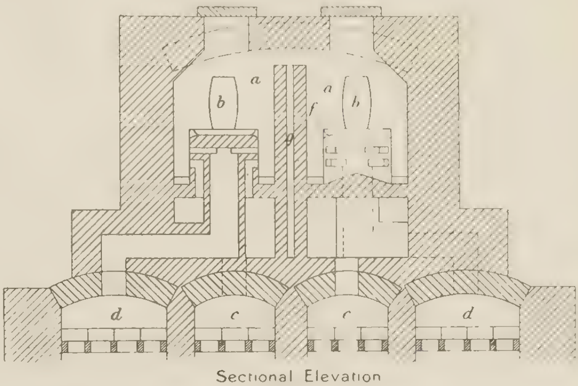


FIG. 16.—Liquid Fuel Furnace with Perforated Crucible Bed.

a, Melting hole; *b*, Crucibles; *c*, Perforated refractory bed; *d*, Inlet; *e*, Outlet flue; *f*, Oil supply; *g*, Air supply.

FIG. 17.—Gas-fired Regenerative Crucible Furnace.

a, *a*, Melting holes; *b*, *b*, Crucibles; *c*, *c*, Gas regenerators; *d*, *d*, Air regenerators; *f*, Dividing wall; *g*, Secondary air supply.



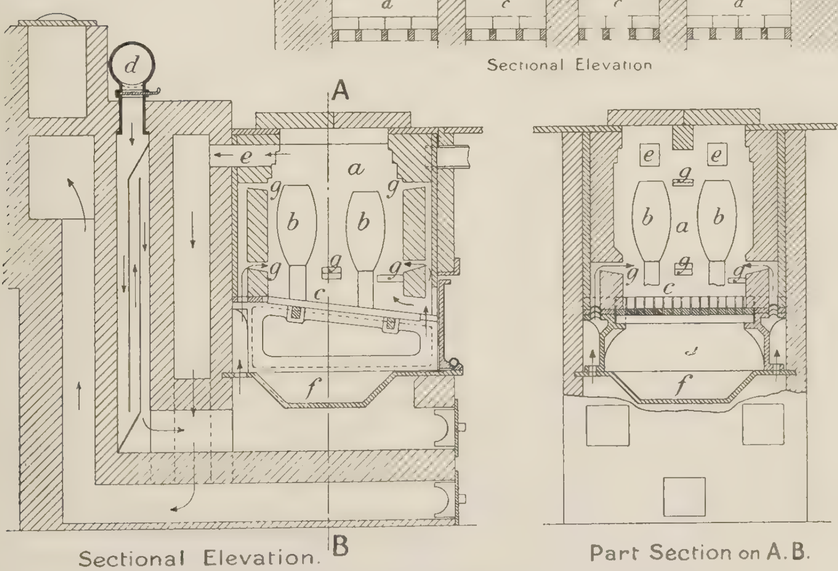
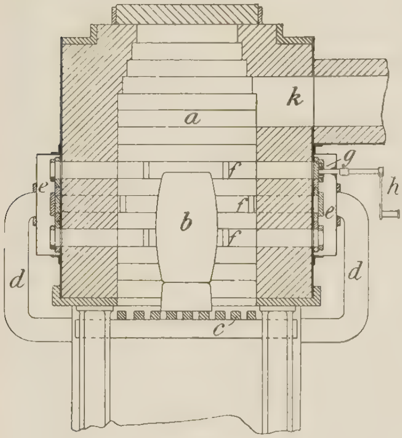


FIG. 18.—Coke-fired Crucible Furnace with Forced Draught.

a Melting hole; *b*, *b*, Crucibles; *c*, Grate bars; *d*, Air inlet; *e*, *e*, Outlet flues; *f*, Ashpan; *g*, *g*, Air ports.

In 1908 William Miller patented a furnace (Fig. 18), in which the air for combustion with the coke fuel is heated in its passage to the underside of the grate bars by means of the waste gases which pass to the chimney through a flue running parallel with the air inlet flue. The pressure of air is regulated according to the temperature required. The air is also directed to the melting chamber through the fire bars and ports to distribute it evenly throughout the furnace. Below the fire grate an ashpan is kept full of water, into which the ashes fall, producing vapour which unites with the air of combustion to accelerate the melting. This furnace is more fully described in Chapter VII.



Sectional Elevation.

FIG. 19.—Coke-fired Crucible Furnace with Forced Draught.

a, Melting hole; *b*, Crucible; *c*, Grate bars; *d*, Air inlet; *e*, Air belt; *f*, Portholes; *g* and *h*, Rack and Handle for regulating air supply; *k*, Outlet flue.

Fig. 19 shows a crucible furnace patented by James W. Chenhall in 1909. The crucible rests on a fireclay block on fire grate bars, from below which air is admitted to the coke surrounding the crucible. Several tiers of draught holes admit heated air at different levels around the crucible. Each tier of holes is surrounded on the outside of the furnace by a band with ports in it, and by means of a rack and handle the air supply can be regulated through the draught holes. Air under pressure is admitted to a belt surrounding the furnace at the level of the air ports, pipe connections being made from the air belt to the closed ashpit for the supply of air through the grate bars to the interior of the furnace. Apart from the grate bars, the general arrangement of ports and air belt is in many respects similar to that found in cupolas for melting iron. A fuller description is given in Chapter VII.

Tilting Oil-fired Furnaces.—Fig. 20 shows a tilting furnace consisting of a simple casing lined with refractory materials, in the body of which are passages conveying air from the outside to the combustion chamber. The air enters through one of the trunnions and passes round the lining in the direction shown by the arrows, mixing with the oil as the spray enters the combustion chamber, and thence to the furnace. The air passages in the lining are made as close to the interior surface as practicable, so that the air may receive as much heat as possible before it mixes with the oil vapour. This furnace was patented in America in 1909 by William Carr.

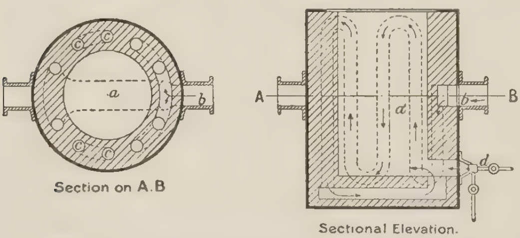


FIG. 20.—Tilting Oil-fired Crucible Furnace.

a, Melting hole; *b*, Air inlet; *c*, Air passage; *d*, Oil jet.

Tilting Oil-fired Furnace with Regenerators.—In the same year William Carr and C. H. Speer patented a tilting crucible furnace, as shown in Fig. 21. The furnace in which the crucible is placed consists of a short and narrow

chamber lined with refractory materials, and connected at each end with regenerators which extend behind the furnace on each side, and through which the heated air is supplied to combine with the oil vapour. The crucible, which has a capacity of about 1000 lbs., is fixed in the melting chamber in such a way

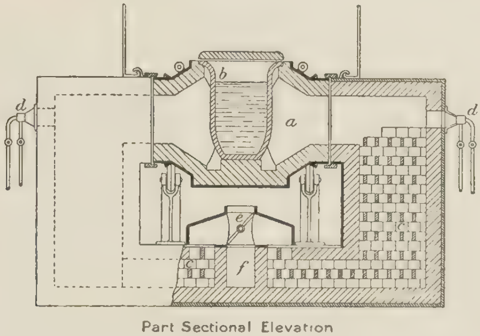


FIG. 21.—Tilting Oil-fired Crucible Furnace with Regenerators.

a, Tilting melting chamber; *b*, Crucible; *c*, *c*, Air regenerators; *d*, *d*, Oil jets; *e*, Reversing valve; *f*, Chimney flue.

as to render unnecessary its removal from the chamber until replaced by a new one. The chamber with crucible can be lifted by a crane and the contents of the crucible poured out. The operation of the furnace is quite simple. After the crucible is charged and the cover attached, the oil flame from the burner on one side is ignited, and passes round the crucible, proceeds into the regenerator, and from thence to the stack through the reversing valves. After 20 minutes the operation is reversed. The air necessary to support combustion is drawn through an air inlet on the side of the reversing valve, passing to the furnace through chequered brickwork.

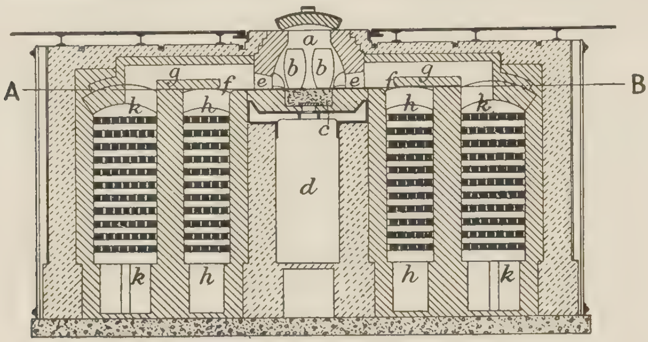
Siemens Gas-fired Crucible Furnaces.—There are two principal types of gas-fired Siemens crucible furnaces used at the present time. Fig. 22 illustrates the furnace which is known as the "ordinary" type, and which differs from the "new form" in having two regenerators on each side of the melting holes for gas and air, instead of one for air only. The gas producer is also built separate from the furnace, whereas in the "new form" Siemens it forms part of the main structure.

In the "ordinary" furnace it will be observed that each melting chamber contains 6 crucibles. Fig. 23 (p. 68) shows sectional elevations and plan of the melting chamber, which is made as small as possible, and arches over the crucibles to throw the heat down upon them. To protect the brickwork of each of the ports in the melting chamber, loose blocks made of high refractory material are fitted over the walls separating the ports from each other. When worn out, these can be replaced more easily than the built-up brickwork, it being necessary to pull down the covering arches to repair the walls. The gases are purposely baffled in their progress around the crucibles, to prevent them from escaping too quickly. This furnace is more fully described in Chapter VIII.

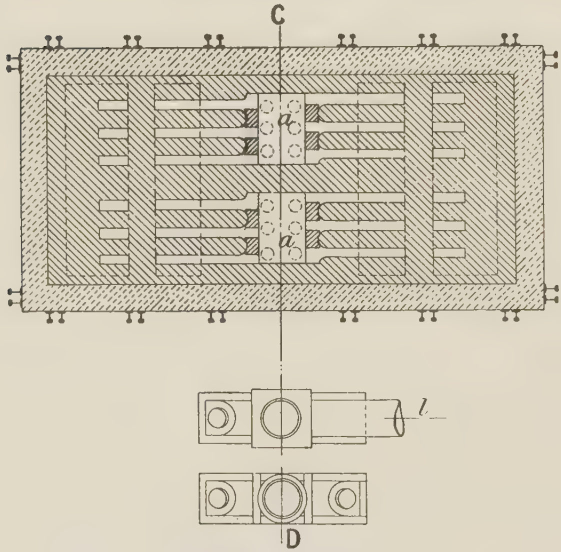
In the "new form" Siemens furnace, shown in Fig. 24 (p. 69), the melting chamber contains 16 crucibles, and the gases travel about 23 feet in their passage through the chamber. To maintain uniform temperature throughout, frequent reversals of the gases are necessary. In the early experiments with the Siemens furnace with long melting chambers, it was found that the charges in the crucibles at the middle were not melted so quickly as those near the ends of the

chambers where the flame was hottest. Perfect control is now obtained by baffling the escape of the gases and by reversing their direction about every 20 minutes. A more complete description of the "New form" furnace is given in Chapter VIII.

Anthracite-fired Crucible Furnaces.—The Anthracite-fired crucible furnace



Sectional Elevation.



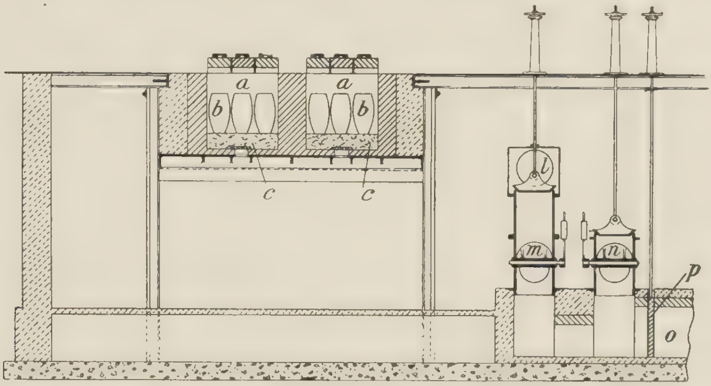
Section on A. B.

FIG. 22.—Siemens Gas-fired Crucible Furnace.

a, *a*, Melting holes; *b*, *b*, Crucibles; *c*, *c*, Coke beds; *d*, Vault; *e*, *e*, Combustion chambers; *f*, *f*, Gas ports; *g*, *g*, Air ports; *h*, *h*, Gas regenerators; *k*, *k*, Air regenerators; *l*, Gas inlet; *m*, Gas reversing valve, *n*, Air reversing valve; *o*, Chimney flue; *p*, Chimney flue damper.

was first developed in America. It differs from the ordinary Huntsman furnace in one or two particulars only:—(1) A much thicker bed of anthracite than of coke is necessary owing to the slow-burning nature of the fuel, and consequently a deeper furnace is required; and (2) the ashpit below the grate is closed, and into this a blast of low-pressure air from a fan is delivered through a 3-inch pipe. The outlet flue in the melting hole through which the waste gases pass is

arranged in the same manner as in the Huntsman furnace, but the waste gases are utilised as a rule for raising steam in boilers which are placed in suitable positions in relation to the furnace to receive the heat.



Section on C.D.

FIG. 22.

Natural-Gas-fired Crucible Furnaces.—In the United States where natural gas is plentiful, crucible furnaces are successfully employed with natural gas as the heating agent, which can be used in most designs of coal-gas-fired furnaces.

General Considerations in the Design of Crucible Furnaces.—From the various types of furnaces described it will be observed that the crucible furnace consists of firebrick chambers of different designs in which are placed crucibles containing the materials to be melted. The heat for melting the contents is either generated in the chamber, or enters and passes through the chamber from an external source.

Ideal Design of Furnace.—The ideal design of crucible furnace recommends itself in that it gives—

1. The greatest output from each crucible in the shortest time.
2. The lowest consumption of fuel per ton of steel melted.
3. The maximum number of heats from each crucible.
4. The maximum endurance of the furnace to save frequent rebuilding.

1. Output of Steel.—To obtain the greatest output from crucibles in the shortest time, the design of the furnace must be such as will concentrate as much heat as possible upon the crucibles without destroying them. This principle has been applied to the various furnaces, viz. :—

(*a*) The single-crucible type of large capacity, where the whole body of heat surrounds and is concentrated upon the crucible.

(*b*) The double-crucible type of chamber in which both crucibles, each of small capacity, are heated.

(*c*) The multi-crucible type of chamber in which several crucibles of small capacity are heated.

2. Fuel Consumption.—The consumption of fuel per ton of steel melted depends on the design of the furnace, as well as upon the calorific value of the fuel and its complete combustion in the proper part of the furnace. The use of coal producer gas, oil under pressure, and forced draught for coke-fired crucible furnaces have done much to effect economies in melting steel in crucibles. The rapid passage of the hot gases through the furnace to the flues

has led to their being used for heating the air which enters and combines with the fuel. In this direction the use of regenerators has brought about the reduction of fuel costs. The size, shape, and number of crucible chambers in furnaces also play an important part in the fuel economy.

3. **Number of Heats from each Crucible.**—The number of heats from each

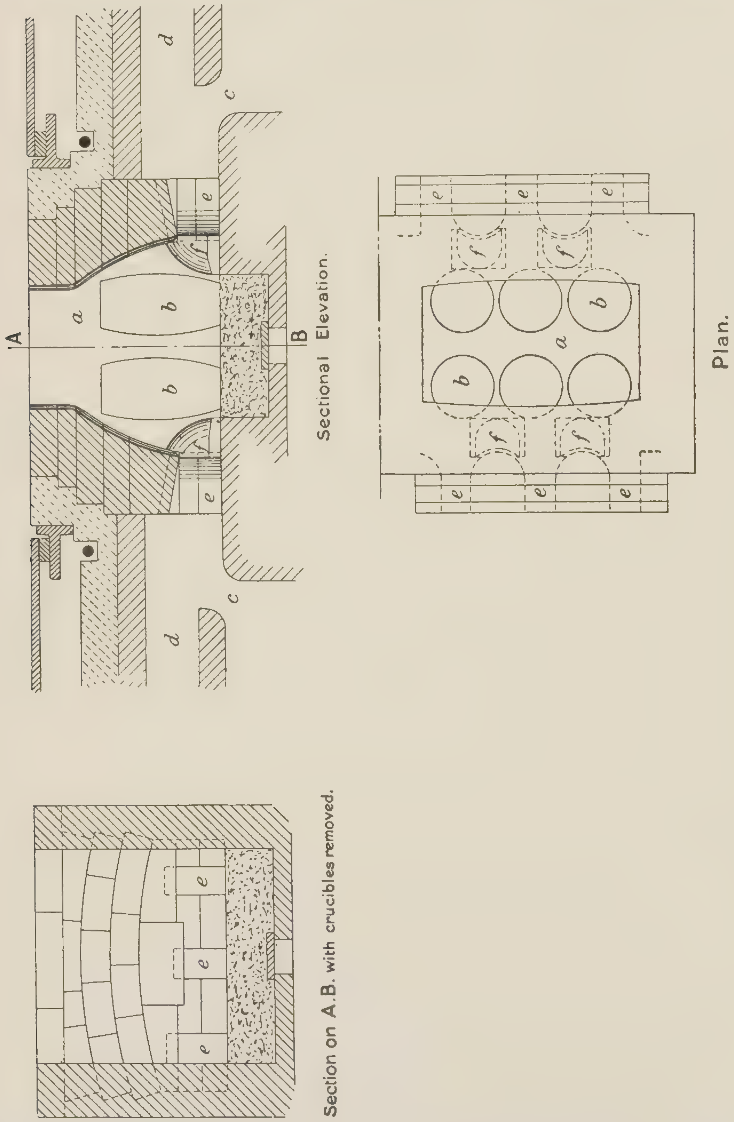


FIG. 23.—Details of Melting Hole of Siemens Gas-fired Crucible Furnace.

a, Melting hole; *b*, *b*, Crucibles; *c*, *c*, Gas ports; *d*, *d*, Air ports; *e*, *e*, Inlet and outlet ports of melting hole; *f*, *f*, Renewable refractory blocks for protecting brickwork around ports.

crucible depends upon the quality, size, and use of the latter. The design of furnace and character of the fuel, as well as the direction of the flame upon the crucibles, influence greatly the life of the crucibles.

4. **Endurance of the Furnace.**—The endurance of a furnace depends,

(*a*) upon its construction, (*b*) upon the fire-resisting qualities of the materials of which it is built, (*c*) upon the intensity and duration of the heat to which it is

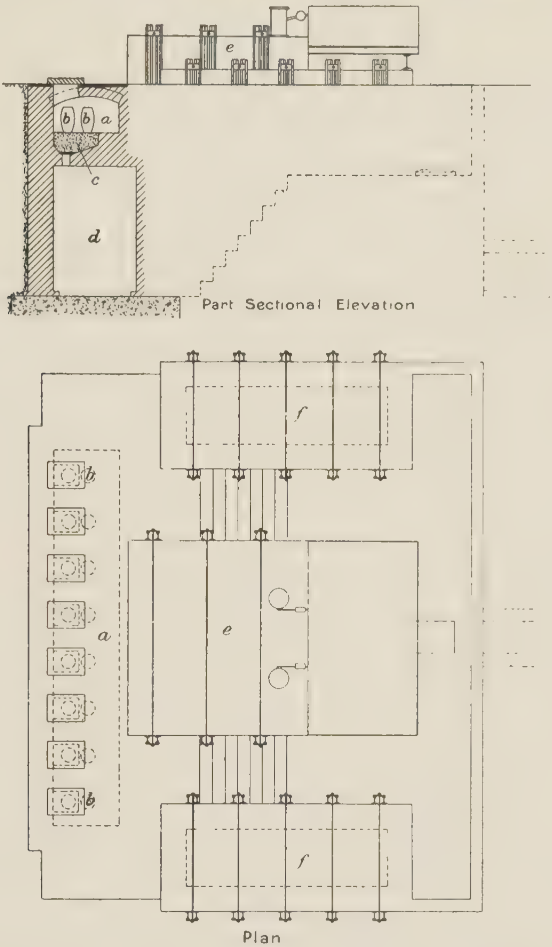


FIG. 24.—"New Form" Siemens Gas-fired Crucible Furnace.

a, Melting chamber; *b*, *b*, Crucibles; *c*, Coke bed; *d*, Vault; *e*, Gas producer; *f*, *f*, Air regenerators.

subjected, and (*d*) upon its intermittent use. The cost of upkeep is therefore a factor of some importance.

CHAPTER V

MANUFACTURE OF CRUCIBLES

CRUCIBLES used in the manufacture of steel are of two kinds:—Clay and Plumbago. For melting pig iron and scrap and other materials for steel castings, plumbago crucibles are found more economical as a rule than clay crucibles. The objection to the absorption of carbon by the charge from the materials composing the pot is sometimes offered as a reason for not using plumbago crucibles. In higher qualities of tool steel making, this point is worthy of consideration, but for melting mixtures for various qualities of castings the plumbago pot is as good as the clay pot. The life of a crucible depends in no small measure upon the human element, for in the hands of some furnace men, crucibles will last 25 per cent. to 50 per cent. longer than in those of others. The average number of heats obtained from a clay crucible of 60 to 80 lbs. capacity for melting tool steel is 3, or one day's work, while for melting pig iron and steel scrap for steel castings, 4 to 5 heats can be obtained by a careful man. The average number of heats obtained, on the other hand, from a plumbago crucible of 60 to 80 lbs. capacity for melting tool steel is 4 to 5, whereas when used for melting mild steel cuttings and scrap for steel castings, 12 to 20 heats may be obtained, and from 20 to 25 heats when a large proportion of pig iron is used in the charge. It is often by observing small matters that the life of crucibles may be prolonged. For instance, with each successive charge of material, the melter reduces the weight of the charge so that the level of the molten steel is different for each melt. This is done to prevent undue chemical action in one place by the slags round the inside of the crucible at the surface of the steel.

The manufacture of crucibles is no small item in the crucible steel industry. In 1894, Mr. Hadfield[1] (now Sir Robert Hadfield) stated that "Sheffield now uses weekly some 14,000 clay crucibles in which to fuse steel," and considering the growth in the industry since then it is only to be expected that this number has greatly increased.

CLAY CRUCIBLES

Sizes of Crucibles.—Crucibles are made in various sizes, although in the Sheffield district the crucibles most commonly used are from 16 inches to 20 inches high and about 9 inches diameter at the largest part.

Materials Used.—The clays used are: China Clay, Stourbridge, Burton and Stannington clays, to which are added small quantities of burnt clay, coke dust, and sometimes old ground pots and cinders. Crucibles intended for the manufacture of steel castings are usually made with a somewhat larger proportion of coke dust than those used for tool-steel, as the addition of coke dust makes the pot more porous and allows for more contraction to withstand the greater variation in temperature to which steel foundry crucibles are subjected during pouring. Again, the crucibles used in a foundry are usually made with a thicker

[1] "Journal Iron and Steel Institute," 1894, II.

edge at the top to enable the pot all the better to withstand the variations in heat; otherwise they would be liable to crack and lose their shape through exposure to the cold air.

Mixing the Materials.—After the materials have been proportioned out, they are thrown together into an open metal frame some 10 feet long, 8 feet wide, and 8 inches to 10 inches deep, placed on the floor. The mixture is then formed into a ring, water is poured in, and the clay is ready for "treading," which is done by the bare feet; the object being to knead all the materials thoroughly together and by squeezing all the air out of the mass, to leave it perfectly homogeneous. Machines have on several occasions been tried for performing this mixing and kneading operation, without satisfactory results.

After the clay has been trodden and turned over for about 4 or 5 hours, it is cut up into pieces and weighed, each piece being sufficient to make one crucible. The clay is then taken and "balled," by lifting the clay above the bench and throwing it down continuously for two or three minutes to remove as far as possible any air still retained in the mass, and to bring it into the requisite shape for making into a crucible.

Moulding Crucibles by Hand.—Generally, crucibles for coke-fired furnaces are made by hand and have a hole left in the bottom after the process of

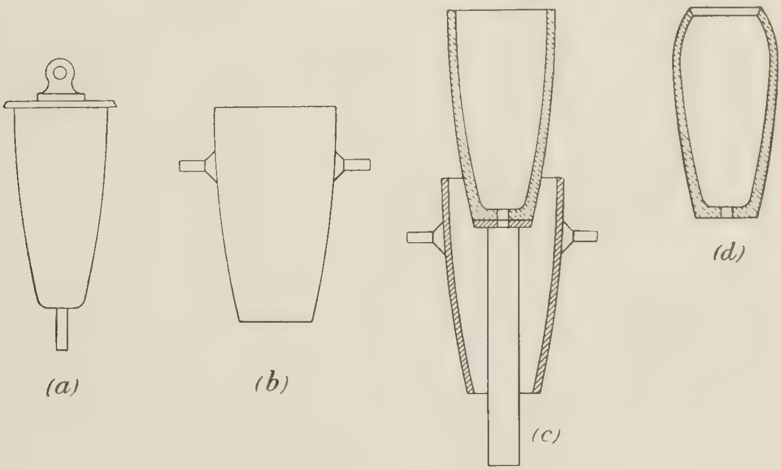


FIG. 25.—Plug and Flask for Moulding Crucibles by Hand.

a, Plug; *b*, Flask; *c*, Method of stripping crucible from flask; *d*, Finished crucible.

making. The moulding is done by means of a "plug" and "flask," Fig. 25, *a* and *b*. The flask has a loose bottom with a hole in the centre which allows the pin at the lower end of the plug to enter and thus ensure the plug and flask being concentric. After the flask has been well oiled, the ball of clay is dropped in, and the plug inserted and worked into the clay until the latter has been forced about halfway up the flask. The plug is then struck on the top with a heavy wooden mallet until the clay is brought level with the top of the flask. Afterwards, the plug is withdrawn and the flask with the newly made crucible inside lifted on to a small post, which allows the flask to drop down, leaving the loose bottom with the crucible upon it, standing on the post; see Fig. 25, *c*. The mouth of the crucible is then pressed inward by what is called a "turning-in dish," to lessen the possibility of spilling the charge when the crucible is in

use, and also to prevent the mouth of the pot from being chipped. Fig. 25, *d*, is a section of a completed clay crucible.

Moulding Crucibles by Machine.—Crucibles are often made by machine, in which case the pots have solid bottoms. Crucibles of this kind are made either in a hydraulic press, or in a screw press. The latter type of machine (Fig. 26) has been made for over 30 years by a Sheffield firm, and is to a considerable

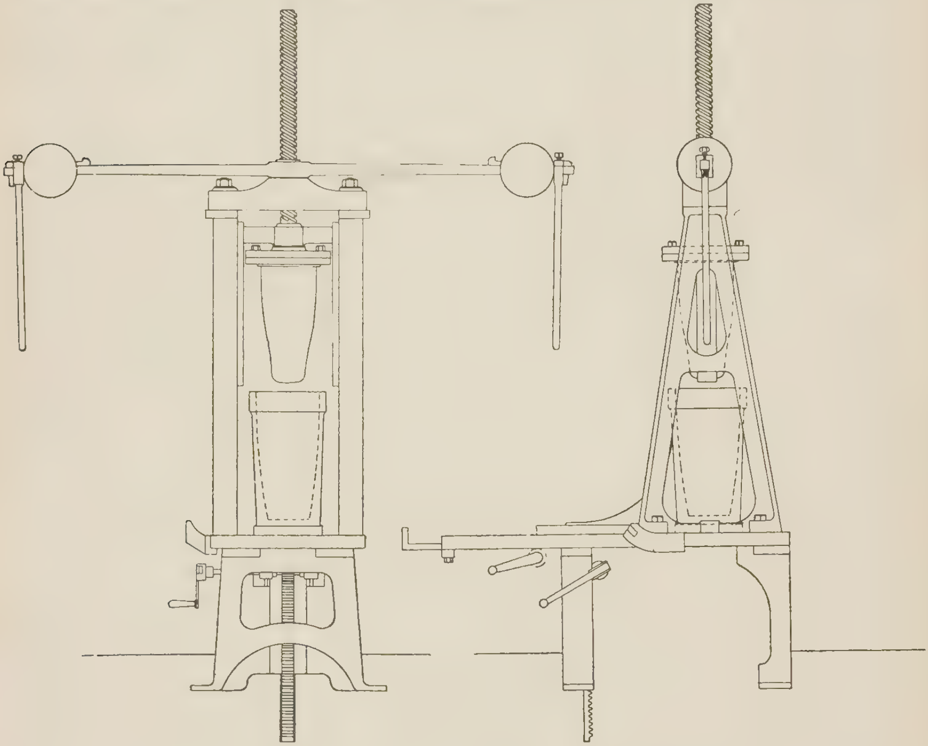


FIG. 26.—Machine for making Crucibles. (Crowley's design.)

extent replacing the plug and flask for making crucibles by hand, although this latter and older method is still commonly used.

Drying Crucibles.—After being moulded, the crucibles have next to be dried, and this operation must be very carefully and gradually performed. In small works this is often done by putting the crucibles in front of the melting hole in the cellar and turning them round as they get warm. A better way is to dry the pots in a shed built at the back of the furnace stack, the crucibles being placed on shelves round the shed (but not on the stack side), which is kept warm by the heat of the stack, gradual drying thus being ensured. The method which finds favour in works where a considerable number of crucibles are used, is to dry the pots in a specially built drying shed heated by gas, and capable of holding 500 to 1000 crucibles.

When thoroughly dried they are removed to shelves carried by the face of the furnace stack inside the melting house, and kept there for three or four weeks to be seasoned.

Annealing Crucibles.—It is most important that the crucible be annealed before use. The grate of an annealing stove (Fig. 27) capable of holding a

sufficient number of crucibles for the day's melting, is covered with a layer of red-hot coke, and upon this the crucibles are placed mouth downwards and surrounded by coke, which is left to burn through, taking about 20 to 24 hours. At the end of this time the crucibles, at a dull red heat, are ready to be transferred to the melting furnace.

Crucible Lids and Stands.—The crucible lids and stands are generally made of an inferior mixture of clay to that used for the crucibles. The method of "treading," however, is the same, and the clay is cut into pieces, and each piece thrown into an iron ring to give it the required shape.

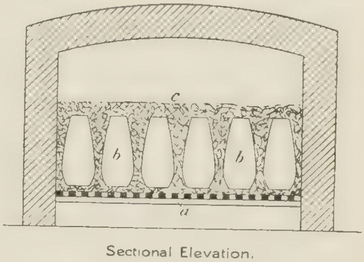


FIG. 27.—Annealing Stove for Crucibles.
a, Grate bars; *b*, *b*, Crucibles; *c*, Coke.

PLUMBAGO CRUCIBLES

In America and on the Continent, plumbago crucibles are more commonly used than in England, and in the United States those of 100 lbs. capacity are generally used.

Materials used.—As a rule, plumbago crucibles are made of a mixture of Ceylon graphite, clay, and pure sand, the final composition having an approximate analysis of—

Carbon, 50 per cent.; Silica, 35 per cent.; Alumina, 11 per cent.; Iron Oxide, etc., 4 per cent.

Preparation of Materials and Manufacture of Crucibles.—The clay used in the manufacture of these crucibles is first dried and ground, and then made into a paste with water to which the graphite and sand are added, the whole being thoroughly mixed. The mass is then allowed to remain for several days in a damp place before being worked up. This latter operation is performed by cutting off a piece from the mass, kneading it, and placing it inside a mould which is spun in a potter's wheel, the inside being formed to the required shape by means of a profiling tool. Any surplus material is afterwards cut away from the rim of the crucible, which is dried for about twenty-four hours at normal atmospheric temperature, and sleeked over. The hygroscopic water is subsequently driven off, the crucibles being maintained at a sufficiently high temperature for about three weeks to allow this to be well carried out. The crucibles are then stacked in "saggers" and annealed for about three days at a temperature of about 800° C. in an annealing oven, at the end of which period they are thoroughly annealed and ready for use.

Styrian Graphite Crucibles.—At Kapfenburg, the principal seat of crucible steel manufacture in the Austrian Alpine region, the crucibles used are made of Styrian graphite, mixed with clays in different proportions. The graphite as used for crucibles contains[1]—

Carbon, 77·8 per cent.; Silica, 13·04 per cent.; Alumina, 6·12 per cent.; Ferric Oxide, 0·44 per cent.; Potash, 0·43 per cent.; Phosphoric Oxide, 0·01 per cent.; Water, 1·95 per cent.

The clays used are dried, crushed to fine powder, then mixed in mixers and worked into a paste in suitable troughs. The moulding of the crucibles is done in power presses. The drying is done very gradually in a room in which special heating apparatus is employed for sending currents of warm air round the shelves on which the crucibles rest.

[1] "School of Mines Quarterly," vol. 29, p. 329.

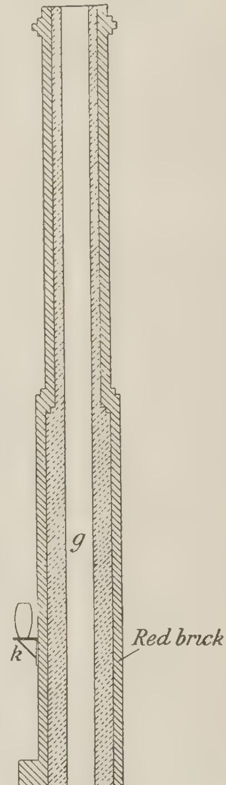
CHAPTER VI

COKE-FIRED CRUCIBLE FURNACE. HUNTSMAN TYPE

Description of the Furnace.—The crucible furnace of the Huntsman type, shown in Fig. 28 and Fig. 29, consists of a series of pot holes spaced about 3 feet apart centre to centre, each made to receive two crucibles. The hole is about 3 feet 6 inches deep from cover to fire bars, 2 feet 3 inches long from back to front, and 1 foot 6 inches wide; this allows of a body of coke a few inches thick round each crucible. The shape of the hole (usually oval) is obtained by ramming moist ganister round a "former," shown in Fig. 30, placed on the fire bars. Round the top of the ganister a few layers of firebricks are so laid as to close in the top of the hole, on which is placed the cover plate. The mouth of the hole, which is on a level with the floor, is about 15 inches by 13 inches, and is covered with a firebrick about 18 inches long by 16 inches wide by 4 inches thick, fastened in a frame. A handle is fixed to the frame, which affords an easy means for its removal.

Operation of the Furnace.—When newly built, the furnace is allowed to dry naturally for some days before any fire is put into it. Heat is usually applied very slowly by means of small wood fires with additions of coke as the drying proceeds. This initial and sometimes tedious part of the work must be carried out carefully to avoid cracks and faulty draught afterwards.

For a furnace which has already been in use, the day's work begins by chipping off from the inside of the hole all the adhering slag from the previous day's melt by means of slagging bars. The fire bars, usually five in



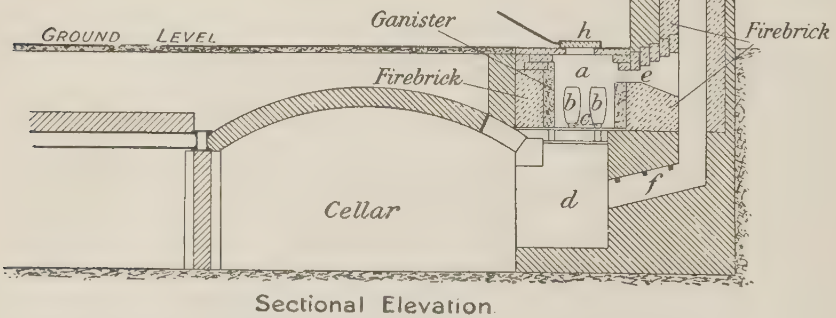


FIG. 28.—Huntsman Coke-fired Crucible Furnace; Modern Type.

a, Melting-hole; *b*, *b*, Crucibles; *c*, Fireclay stands; *d*, Ashpit; *e*, Chimney-flue; *f*, Auxiliary chimney-flue; *g*, Chimney; *h*, Melting hole cover; *k*, Shelf for drying crucibles.

number, are then put in, spaced an equal distance apart, the fireclay crucible stands placed on them, and the bars covered over with hot coke. The crucibles

FIG. 29.—Crucible Melting Furnaces (Messrs. Samuel Osborn & Co., Ltd., Sheffield).

are then taken from the annealing furnace and each placed on its stand, the holes being filled up with coke to the level of the top of the crucibles. When the fuel

burns through, the crucibles are at a white heat, and by throwing a small quantity of sand into them, they are fused on to their fireclay stands and the hole in the bottom of each filled up. As soon as the sand is frittered to the crucible, the "puller-out" charges the material by means of a "charger," shown in Fig. 31, which is fitted over the mouth of the crucible. The lid is then put on, the hole filled up with coke, the cover placed over the hole, and the fire left to burn through. This fire is called the "steeling" fire, and usually requires to be renewed three times after it has burned through before the charge is ready. For the second heat two fires, and for the third heat one fire, usually suffice.

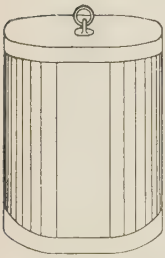


FIG. 30.—Melting-hole Former.

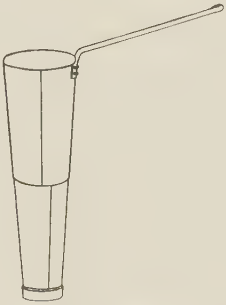


FIG. 31.—Charger for filling Crucibles.

During the intervals of coking and casting the annealing furnace is filled with crucibles for the next day's working and lit off, and if ingots are to be cast, the ingot moulds are prepared.

The control of the furnace is under the charge of the head melter, who with the "puller out" regulates the rate of melting. Each pothole has a separate flue to the chimney, as well as one in the cellar which admits air to the pothole. By the use of a brick damper in each, the heat can be regulated at the will of the operator. If the melting is proceeding more quickly in one pothole than in another, the brick is placed in the flue between the pothole and the chimney. If the melting is proceeding too slowly, the brick in the cellar flue is drawn to admit more air.

When the steel is properly melted and any necessary ferro-alloys and other additions have been added and melted, the "puller-out," with arms and legs

FIG. 32.—Pulling-out Tongs.

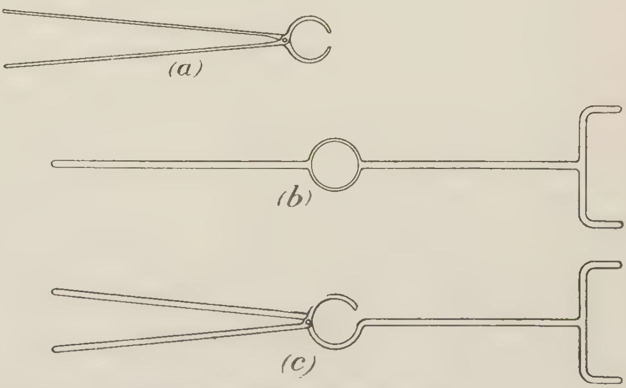


FIG. 33.—(*a*) Single Tongs for carrying Crucibles; (*b*) and (*c*) Double-handled Tongs for carrying Crucibles.

covered with wet sacking, introduces the pulling-out tongs (see Fig. 32), and lifts the pot out on to the floor. After the removal of the clay lid, and the

skimming of the slag from the metal with a "mop" (*i.e.* a thin bar with a knob of slag already attached to the end) the steel is ready for pouring into the moulds, the crucible being handled by means of single tongs (Fig 33, *a*) or double-handled carrier (Fig. 33, *b* and *c*). As soon as they are empty, the crucibles are usually replaced in the furnace and brought up to a white heat before being charged again. The first heat takes from 4 to 5 hours, the second heat about 3½ hours, and the third heat about 2½ hours, the times varying according to the class of material being melted and the degree of refinement required.

Output and Cost of the Furnace.—To produce 25 tons of liquid steel per week, or 1200 tons per year, it is necessary to have at least 12 melting holes, working continuously from Monday morning until Saturday midday. Each hole is made to contain two crucibles having an average capacity of 75 lbs. each.

The cost of a furnace of this size is approximately £900.

∴ Annual charge for depreciation	@ 10% =	£90
" " interest	@ 5% =	£45
	Total charge	£135

$$\text{Cost per ton of liquid steel} = \frac{135 \times 20}{1200} = 2s.\ 3d.$$

Working Costs (per ton of liquid steel for carbon steel castings)

Cost of Repairs.—In Sheffield and other districts it is usual to reline with ganister every three to four weeks furnaces which are in operation during day and night shifts from Monday until Saturday each week. It is false economy to continue using a melting hole when the lining is so large as to waste fuel. This is what happens as the melting holes become large. Every time a melting hole is lined, the brickwork round the top of the furnace is repaired or renewed, and every year the furnace walls and flue outlets are rebuilt. The total annual cost for repairs varies with the conditions of working the furnace and the quality and cost of the refractories used. The average cost, however, for a 12-hole furnace is approximately 4*s*. 6*d*. per ton of steel melted.

Cost of Fuel.—As the waste heat from the fuel is not utilised in the Huntsman Furnace, the average consumption of coke per ton of steel melted is higher than in some of the other types of furnaces. The amount consumed depends, of course, upon the nature of the materials melted.

When melting materials for the manufacture of tool steel, it is necessary to use the best washed coke in which a minimum percentage of sulphur is found. The consumption of coke per ton of steel melted is 2½ to 3½ tons. When melting scrap steel and pig iron for steel castings of ordinary quality, the consumption of coke averages 1¾ tons per ton of steel. Thus with coke at 23*s*. 6*d*. per ton, the cost of fuel per ton of steel melted = £2 1*s*. 1*d*. approximately.

Cost of Crucibles.—Both clay and plumbago crucibles are used. In the Sheffield district clay crucibles are very largely used, as many years' practice has made the Sheffield workmen expert in producing crucibles of good quality, and at a low cost. When melting mild steel scrap with a small proportion of pig iron for the manufacture of steel castings, an average of 3 to 5 heats are melted in each clay crucible, whereas a plumbago crucible of good quality will stand an average of 15 melts.

The cost of clay crucibles per ton of steel melted is taken at 10*s*. 6*d*. approximately.

The number of plumbago crucibles required per ton $= \frac{2240}{75 \times 15} = 2$ (nearly), and at 9*s*. 6*d*. each, the cost of plumbago crucibles per ton of steel melted = 19*s*. approximately.

Cost of Labour.—No uniform system is adopted for paying the men employed on crucible furnaces. Some firms work on the premium system, paying a daily wage, with so much extra per ton of good steel produced. Other firms adopt piece-work systems, paying so much to the melter or the one in charge of the furnace, while he in turn employs and pays his gang. Other firms again pay their men a definite wage per shift, with or without a bonus on any saving effected in the coke consumption.

The following hands are employed per shift for operating a 12-hole furnace :—

One melter.
Two "pullers-out."
Two coke wheelers.
One labourer or odd-man.
One cellar lad.

The charges are weighed by the melter, who is also in charge of the furnace.

The "pullers-out" watch the melting holes, add coke when required, and when the steel is melted pull the crucibles from the furnace.

The coke wheelers bring the coke from the bins to the furnace and help in preparing the ingot moulds if tool steel is being made.

The odd-man assists generally, and attends to the crucible-annealing furnace.

The cellar lad is employed making lids and stands, and gives warning of running crucibles, etc.

At different furnaces, even in the same district, the duties of the gang are not the same, so that the above routine is variable. The total number of hands employed, however, is about the same for like furnaces.

The cost of labour is approximately as follows :—

	Day Shift. £	s.	d.	Night Shift. £	s.	d.
One melter	0	7	6	0	9	0
Two pullers-out	0	13	0	0	15	0
Two coke wheelers	0	10	0	0	12	0
One labourer	0	5	0	0	6	0
One cellar lad	0	3	0	0	3	6
Total	£1	18	6	Total £2	5	6

	£	s.	d.
The total weekly wages =	£22	19	0
Adding 100% as part expenses for Foremen, Chemists and Management	£22	19	0
Total	£45	18	0

∴ Cost of labour per ton of steel melted $= \frac{£45\ 18\ 0}{25} = £1\ 16\ 9$

Cost of Raw Materials.—Assuming that the quality of scrap and pig iron

used will produce castings of good quality for ordinary general purposes, the following is a typical charge:—

60 lbs. of mixed steel scrap, 0·15% carbon	@ £4 0 0 ton.
12 lbs. " steel castings scrap, 0·25% carbon	@ £4 0 0 ton.
5 lbs. " hematite pig (broken), 4% carbon	@ £4 10 0 ton.

The cost of melted steel—

	£	s.	d.
Raw material	4	0	8
Aluminium 1 lb.	0	0	7
Plus 2% loss in melting	0	1	8
Total	£4	2	11

Summary of Costs.

Cost of Furnace £900.

	£	s.	d.
Depreciation and Interest	0	2	3
Repairs	0	4	6
Fuel	2	1	1
Crucibles	0	19	0
Labour	1	16	9
Raw Materials (including additions and loss)	4	2	11
Total cost per ton of liquid steel .	£9	6	6

Crucible Furnace with Four Crucibles in Each Hole.

Description of the Furnace.—For small foundries making steel castings of ordinary quality for Colliery, Railway, Marine and General Engineering work, it is not uncommon to use furnaces with melting holes each capable of taking 4 crucibles. These are designed as a rule to take crucibles from 60 to 100 lbs. capacity. Fig. 34 shows sectional plan and elevation of the melting hole of the furnace. The design differs from that of the Huntsman type principally in the form of the melting chamber, which in plan is the shape of a square with rounded corners, the object being to provide an uniform space for fuel all round the 4 crucibles. The furnaces are built as a rule with a number of melting holes connected to one stack, the regulation of the draught to each being made by dampers in the flues. The cellars below the furnace floor for access to the ashpits, are built in a similar way to those of the ordinary Huntsman furnace.

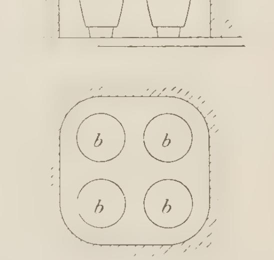


Fig. 34.—Coke-fired Crucible Melting Hole for four Crucibles.

a, Melting hole; *b*, Crucibles; *c*, Outlet flue.

Operation of the Furnace.—When working the furnace on day shift only, it is raised to a high temperature each morning before the crucibles are introduced. The four crucibles are placed close to each other and brought to a good heat before being charged with the raw materials. When properly packed, a clay lid is placed on the top of each crucible, and the melting hole is filled with coke all round the crucibles and up to the top of the furnace. During the melt an examination is made from time to time, to find what progress is being made;

sometimes the crucible is pulled out for this purpose, although more frequently the state of the melt can be determined by means of a small iron rod which the melter inserts in the molten steel. He can judge very nearly the temperature of the material by the appearance of the rod after it is taken out of the molten steel. The first melt takes about 4 hours before the crucibles are ready for pulling out. As a rule three heats are obtained during the day shift. When the crucibles are removed from each melting hole, the fires are cleaned immediately and made ready to receive the empty crucibles again. The second and third heats are melted more quickly, the average time taken being about 3 hours for each heat.

Output and Cost of the Furnace.—Using crucibles yielding on an average 75 lbs. of steel each melt, the daily output (working day shift only) from each melting hole is $75 \times 4 \times 3 = 900$ lbs., so that twelve holes in regular operation would yield $4\frac{1}{2}$ tons of liquid steel per day, or 25 tons per week. Such a furnace, having flues connected with one main stack would cost with stack about £1200.

∴ Annual charge for depreciation	@ 10%	=	£120
,, ,, interest	@ 5%	=	60
Total charge . . .			£180

$$\text{Cost per ton of liquid steel} = \frac{180 \times 20}{1200} = 3s.$$

Working Costs (per ton of liquid steel for carbon steel castings)

Cost of Repairs.—Every four to five weeks the melting holes are relined with ganister and the brickwork around the top replaced. Every twelve months the walls and arches are rebuilt entirely, together with part of the flues nearest the melting holes. The average total cost of monthly and annual repairs is approximately 5*s.* per ton of steel melted.

Cost of Fuel.—By reason of the compactness of the melting holes, less fuel is used than in the ordinary Huntsman furnace dealing with the same raw materials. The average consumption of coke is $1\frac{1}{4}$ tons per ton of steel melted, when charges of scrap steel and pig iron are used. Taking coke at 23*s.* 6*d.* per ton, the cost per ton of steel melted = approximately £1 9*s.* 4*d.*

Cost of Crucibles.—By using good quality plumbago crucibles carefully, as many as 20 to 25 heats have been obtained from one crucible when melting scrap steel and pig iron. The average number of heats, however, is 15, or an equivalent of 1125 lbs. of steel per crucible. The number of crucibles required per ton of steel $= \frac{2240}{1125} = 2$ (nearly).

Therefore the cost per ton of steel melted when the price of crucibles is taken @ 9*s.* 6*d.* each = approximately 19*s.*

Cost of Labour.—The gang employed consists of the following :—

	£	*s.*	*d.*
One teemer	0	7	6
Three "pullers-out" @ 6*s.* 6*d.* each	0	19	6
Eight labourers @ 5*s.* each	2	0	0
Total	£3	7	0
Part expenses for Foreman, Chemist and Management .	3	7	0
Total cost per day for output of $4\frac{1}{2}$ tons .	£6	14	0

∴ Cost of labour per ton of steel melted = approximately £1 10*s.*

Cost of Raw Materials.—The cost of raw materials is taken at £4 2*s.* 11*d.* per ton of steel melted.

Summary of Costs.

Cost of Furnace, £1200.

	£	*s.*	*d.*
Depreciation and Interest	0	3	0
Repairs	0	5	0
Fuel	1	9	4
Crucibles	0	19	0
Labour and Management	1	10	0
Raw Materials (including additions and loss)	4	2	11
Total cost per ton of Liquid Steel	£8	9	3

CHAPTER VII

COKE-FIRED CRUCIBLE FURNACES WITH FORCED DRAUGHT

THE Miller, Radio, and Lindemann furnaces described in this chapter belong to the forced draught type of crucible furnaces, and have been designed with the object of obtaining more rapid melting and a lower consumption of fuel than in the ordinary coke-fired furnaces. To this end the waste heat from the melting hole is utilised for heating the air which is forced under pressure into the furnace through the flues surrounding it, which perform to some extent the functions of the Siemens regenerator.

THE MILLER FURNACE

Description of the Furnace.—Sectional elevations of the Miller Crucible Furnace are shown in Fig. 35. The manner in which the flues are constructed

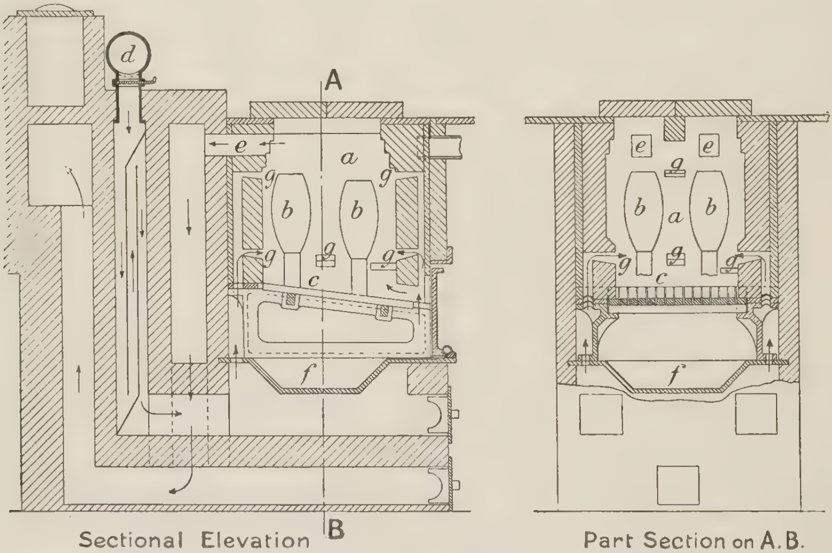


FIG. 35.—Coke-fired Crucible Furnace with Forced Draught.

a, Melting hole; *b*, *b*, Crucibles; *c*, Grate bars; *d*, Air inlet; *e*, *e*, Outlet flues; *f*, Ashpan; *g*, *g*, Air ports.

forms the special feature of this furnace. Inside the outer lining of firebrick is fitted a metal casing, which is lined with fireclay and magnesite. The bottom is

supported on brackets in which are fitted the bearer bars that carry the fire bars forming the grate. Just below the grate is the ashpan, which rests on fire-brick. It contains water for cooling the ashes as they fall, causing vapour to rise and mix with the air, which assists in the combustion of the gases in the furnace. The direction of the heated air is indicated by arrows on the illustrations. The amount of air is regulated before it passes through the inlet flue, grate, and port-holes to the melting chamber. As the outlet flues become hot from the gases passing to the chimney, the air of combustion is heated, with the result that the cost of fuel is less than that of the ordinary coke furnace.

Operation of the Furnace.—In starting up a new furnace, the general practice of allowing the brickwork to dry naturally before introducing a fire is observed. The drying being thoroughly done, the furnace is heated with wood and coke until a melting heat is reached. The charged crucibles are then placed on fire-clay blocks, which rest upon the fire-grate bars. The melting hole is filled with coke closely packed around the crucibles. A cover closes the opening at the top of the melting hole; each crucible also has its own lid. The blast is turned on, and in about two hours a charge of mild steel scrap weighing 75 lbs. can be melted. The scrap melted in this time contains from 0·1 to 0·15 per cent. carbon. The pressure of the blast can be regulated to vary the temperature of the furnace; the pressure found most suitable for melting mild steel is 4 to 5 inches water gauge. During the melting, the water in the ashpan is renewed from a pipe which passes into a chamber below the bars. The examination of the crucibles as the melting proceeds, and the pulling out and finishing of the steel with suitable additions, are conducted in the ordinary manner as in the Huntsman furnace.

Output and Cost of the Furnace.—For the sake of comparison, the cost is based on a weekly output of 25 tons of liquid steel. Although as many as 5 heats have been obtained in a day of 11 hours, it is assumed that 3 heats could be obtained regularly from one melting hole, containing 4 pots, each with an average capacity of 75 lbs., that is, a total of 900 lbs. of steel per hole per day of 10 hours; therefore, 12 melting holes would produce $4\frac{1}{2}$ tons per day, or 25 tons per week. The annual output would therefore be 1200 tons in 48 weeks.

The approximate cost of each 4-hole crucible furnace when a battery of 12 melting-holes is installed, is £200, including royalty. The total cost is therefore £2400. Taking the usual figures for depreciation and interest:—

Annual charge for depreciation @ 10%	. . . .	= £240
,, ,, interest @ 5%	. . . .	= £120
Total charge	. . .	£360

$$\text{Cost per ton of liquid steel} = \frac{360 \times 20}{1200} = 6s.$$

Working Costs (per Ton of Liquid Steel for Carbon Steel Castings)

Cost of Repairs.—This item is rather more than in the ordinary Huntsman furnace, as the cutting action of the blast at the port holes necessitates more frequent repairs. About every 3 weeks small repairs are made, and the lining requires to be renewed entirely every 6 weeks. The annual cost of repairs is approximately £330.

$$\therefore \text{Cost of repairs per ton of steel melted} = \frac{330 \times 20}{1200} = 5s.\ 6d.$$

Cost of Fuel.—The average coke consumption per ton of mild steel scrap

melted equals 30 cwts. Taking the price of coke at 23*s.* 6*d.* per ton, the cost of fuel per ton of steel melted = £1 15*s.* 3*d.*

Cost of Crucibles.—The rapid melting of the charge has a corresponding effect upon the crucibles. The number of heats obtained varies to some extent, but when using good plumbago crucibles an average of 10 heats can be melted in one crucible of 75 lbs. average capacity, or a total of 750 lbs. of steel. The number used per ton therefore = $\frac{2240}{750}$ = approximately 3. Taking the price of crucibles at 9*s.* 6*d.* each, the cost of crucibles per ton of steel melted = £1 8*s.* 6*d.*

Cost of Labour.—One puller-out and two labourers are required for two melting holes. They see to the work of charging, stoking, and teeming. On the following basis of payment the cost is:—

	£	s.	d.
6 pullers-out @ 6*s.* 6*d.* per day . . . . . . =	1	19	0
12 labourers @ 5*s.* per day . . . . =	3	0	0
Part cost of foreman, chemist, and management =	4	19	0
Total . . .	£9	18	0

$$\therefore \text{ Cost of labour per ton of steel melted} = \frac{£9\ 18s.}{4\frac{1}{2}} = £2\ 4s.$$

Cost of Raw Materials.—This depends on the quality of the scrap and other materials used in the charge, but assuming that they are the same as have been taken for the manufacture of steel castings in the other furnaces, the price per ton would be £4 2*s.* 11*d.*

Summary of Costs.

Cost of furnaces, £2400.

	£	s.	d.
Depreciation and interest	0	6	0
Repairs	0	5	6
Fuel	1	15	3
Crucibles	1	8	6
Forced draught (charge for)	0	1	3
Labour	2	4	0
Raw materials (including additions and loss) . .	4	2	11
Total cost per ton of liquid steel . . .	£10	3	5

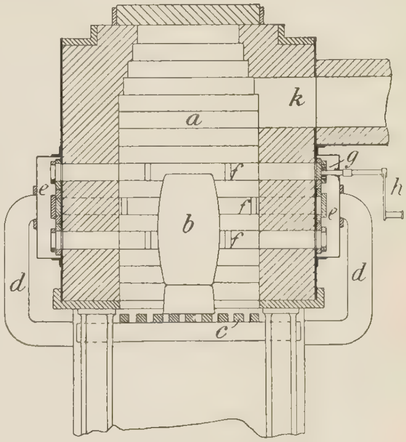
The above furnace is perhaps of more use in melting additions for steel manufactured in larger plants operating the Bessemer, Siemens, and other processes. It is at present used successfully in making steel for automobiles and similar work. It is the patent of Mr. William Miller, of the Mild Steel Castings Co., Ltd.

The Radio Furnace

Description of the Furnace.—Fig. 36 is a sectional elevation of the furnace. It consists of a cylindrical casing lined with firebrick or ganister, through which a series of tiers of draught holes convey heated air to the coke surrounding the crucible or crucibles. When working the furnace with natural draught, the air is drawn into the furnace by the chimney draught, but a fan is used when the air is supplied to the furnace under pressure. The air is conveyed through a pipe

from the fan to an air belt which surrounds the port holes, and thence through the lining to the furnace. Pipe connections are also carried from the air belt to the closed ashpit below the furnace, so that air may be forced through the grate bars into the furnace. The amount of air delivered to the furnace is regulated by means of a rack and handle for each tier of holes, which move bands in the air belt surrounding the furnace, and in which there are port holes.

Operation of the Furnace.—It requires very little skill to work this furnace. When the lining is thoroughly heated with wood and coke, the crucible or crucibles are placed on fireclay blocks on the fire-grate bars, the furnace is packed with coke, and the crucibles charged and closed. After the cover is placed on the top of the furnace, a gentle blast is applied if the natural draught is insufficient, and the process of melting begins. Coke is added from time to time during the $2\frac{1}{2}$ hours required to melt the charge. The crucible is examined during the process to see how the melting is proceeding. When the charge is ready, the crucible is lifted from the furnace with a pair of tongs in the ordinary way, and teemed into moulds as desired.



Sectional Elevation.

FIG. 36.—Coke-fired Crucible Furnace with Forced Draught.

a, Melting hole; *b*, Crucible; *c*, Grate bars; *d*, Air inlet; *e*, Air belt; *f*, Portholes; *g* and *h*, Rack and Handle for regulating air supply; *k*, Outlet flue.

Output and Cost of the Furnace.—From one furnace containing 3 crucibles, each having an average capacity of 85 lbs., about 9 cwts. of mild steel or wrought-iron scrap can be melted per day of 10 hours, that is, 4 heats are obtained per day. Assuming an output of 25 tons of molten steel per week (= 1200 tons per year of 48 weeks), 10 separate furnaces holding 3 crucibles each would be required, or two blocks, each having 5 melting holes with a capacity for 15 crucibles per block.

The cost of the two blocks, with the necessary chimney, and including royalty, is approximately £700.

∴ Annual charge for depeciation @ 10%	= £70
,, ,, interest @ 5%	= £35
Total charge . . .	£105

$$\text{Cost per ton of liquid steel} = \frac{105 \times 20}{1200} = 1s.\ 9d.$$

Working Costs (per Ton of Liquid Steel for Carbon Steel Castings)

Cost of Repairs.—As the melting of the raw materials is carried out rapidly, the lining of the furnace requires to be renewed frequently. Every few weeks a new lining is required, and, taken throughout the year, the total cost of repairs amounts to approximately 5*s.* per ton of steel melted.

Cost of Fuel.—Ordinary gasworks coke is used in this furnace. It is necessary, however, to avoid using coke containing a high percentage of ash,

which would mean constant clinkering of the grate bars, and more repairs to the furnace. When using gas coke, about 2 tons are required per ton of steel melted. Taking the coke at 15*s.* per ton, the cost of fuel per ton of steel melted = £1 10*s.*

Cost of Crucibles.—An average of 10 heats is obtained from the best quality plumbago crucibles when melting mild steel scrap, or a total of 850 lbs. of steel per crucible. Therefore, the number of crucibles required per ton of steel melted $= \frac{2240}{850} = 2{\cdot}63$.

Taking the crucibles at 13*s.* 6*d.* each, their cost per ton of steel melted $= 13/6 \times 2{\cdot}63 =$ £1 15*s.* 6*d.*

Cost of Labour.—12 men are required to operate 10 melting holes successfully, the work including wheeling and charging coke, charging crucibles, pulling-out and teeming.

On the following basis of payment the cost is as follows:—

	£	*s.*	*d.*
4 pullers-out @ 6*s.* 6*d.* per day . . . . =	1	6	0
8 labourers @ 5*s.* per day . . . . =	2	0	0
Part of cost of foreman, chemist, and management . . =	3	6	0
Total . . .	£6	12	0

∴ Cost of labour per ton of steel melted $= \dfrac{£6\ \ 12s.\ \ 0d.}{4\frac{1}{2}} =$ £1 9*s.* 4*d.*

Cost of Raw Materials.—For comparison, this price is taken at £4 2*s.* 11*d.* per ton as in the other furnaces.

Summary of Costs.

Cost of furnaces, £700

	£	*s.*	*d.*
Depreciation and interest	0	1	9
Repairs	0	5	0
Fuel	1	10	0
Crucibles	1	15	6
Forced draught (charge for)	0	1	3
Labour	1	9	4
Raw materials (including additions and loss)	4	2	11
Total cost per ton of liquid steel . . .	£9	5	9

The price of steel scrap varies considerably in different districts and at different times. Some users of this furnace produce good quality steel castings from scrap for which £3 0*s.* 0*d.* to £3 10*s.* 0*d.* per ton has been paid, instead of £4 0*s.* 0*d.*, the figure taken upon which the raw material price is based. It does not follow, however, that good quality castings could not be produced equally well in the other types of furnaces described, with the same quality of scrap.

This furnace, patented in 1909 by Mr. James Chenall, M.Inst.C.E., is also well adapted for melting physics for larger steel plants as well as steel for ordinary castings in regular quantities.

The Lindemann Furnace

Descripton of the Furnace.—The furnace consists of a double-walled iron casing lined with firebrick, with a hollow grate on which the crucibles rest. See

Fig. 37, which shows a sectional elevation of the furnace. Between the walls of the casing are partitions of channel iron, open at one side, and so arranged that the open side of each partition is opposite that of the partition placed above it. At the top of the casing, a pipe admits air under pressure into the hollow casing, a valve serving to give the required regulation. The air is delivered to the furnace from a fan, and passes from the top to the bottom of the hollow casing in a zigzag direction, thence to the hollow grate. The air therefore becomes heated in its passage to the grate, and also serves to cool the furnace

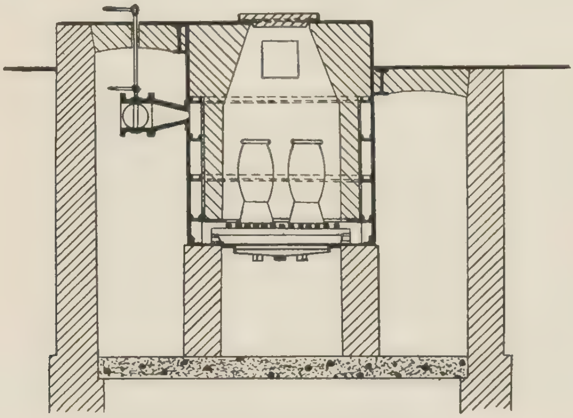


FIG. 37.—The Lindemann Furnace.

wall at the same time. The fuel used is coke, and the products of combustion pass away through the outlet at the top of the chimney.

Operation of the Furnace.—The furnace is operated in a similar manner to the two furnaces previously described in this chapter.

Output and Cost of the Furnace.—The capital outlay for a furnace capable of an output of from 100 to 120 tons in 250 working days is approximately £475.

Summary of Costs for Melting 220 lbs. of Steel.

	£	*s.*	*d.*
220 lbs. materials	0	6	10
1 crucible, @ 8/10 each	0	8	10
440 lbs. coke equal to 200% of materials melted, @ 24/8 ton	0	4	10
Furnace repairs	0	1	11½
Cost of running fan	0	0	6
Melter and other wages	0	1	11½
Additions and other materials	0	1	0
Depreciation and interest = 15% on capital	0	1	6
Total	£1	7	5

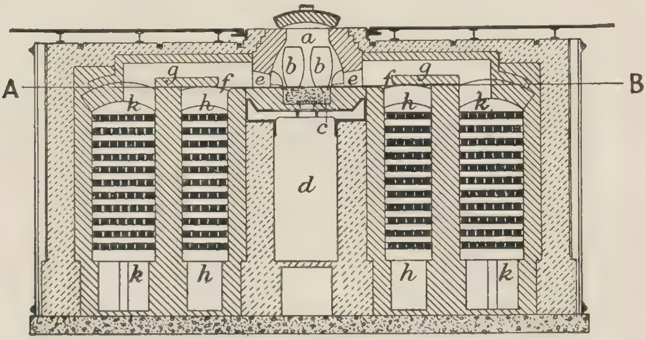
Or approximately £13 14*s.* 2*d.* per ton of liquid steel.

The above figures are for conditions which hold good in Middle Germany, particulars of which were supplied by Mr. Robert Lindemann.

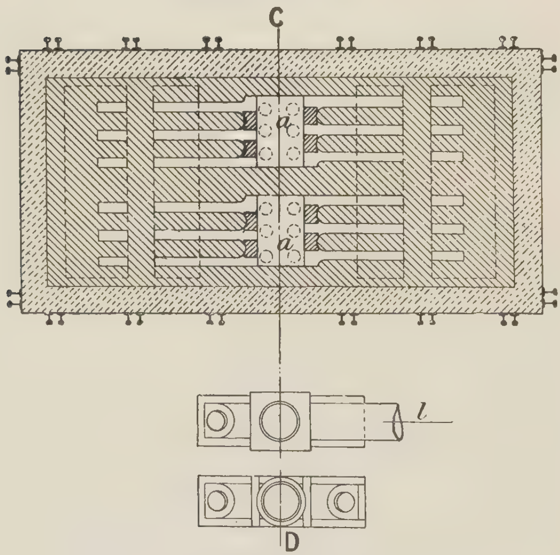
CHAPTER VIII

GAS-FIRED CRUCIBLE FURNACES

THE gas-fired crucible furnaces in Britain, America, and on the Continent are either of the Siemens regenerative type or modifications of it.



Sectional Elevation.

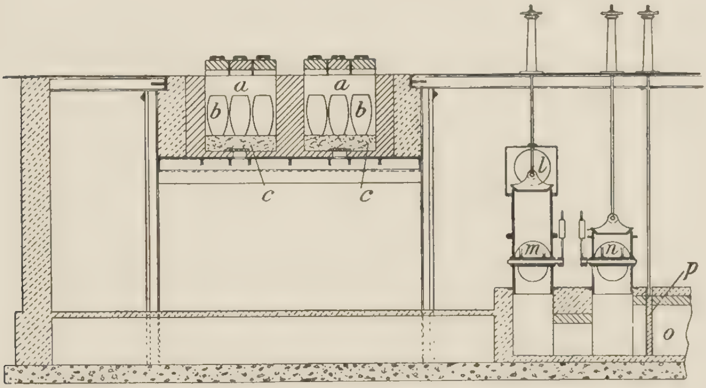


Section on A. B.

FIG. 38.—Siemens Gas-fired Crucible Furnace.

c, *a*, Melting holes; *b*, *b*, Crucibles; *c*, *c*, Coke beds; *d*, Vault; *e*, *e*, Combustion chambers; *f*, *f*, Gas ports; *g*, *g*, Air ports; *h*, *h*, Gas regenerators; *k*, *k*, Air regenerators; *l*, Gas inlet; *m*, Gas reversing valve; *n*, Air reversing valve; *o*, Chimney flue; *p*, Chimney flue damper.

The principle of utilising the waste heat from the melting holes for heating the air which mixes with the producer gas for melting, has been applied since 1866 to this form of furnace. It is said that one of the first Siemens regenerators was applied to the crucible furnace. The degree of accuracy with which regenerators can now be built is very much higher than obtained originally, the result being greater efficiency in working. The "ordinary-form" furnace is still used in this country as well as in America and on the Continent, although the "new-form" Siemens furnace is gradually replacing it.



Section on C.D

FIG. 38.

"ORDINARY-FORM" SIEMENS FURNACE

Description of the Furnace.—The construction of this furnace is shown in Fig. 38, whilst Fig. 39 shows larger sectional views of the melting chamber. This furnace consists of two or more melting pot-holes, on each side of which are two regenerators for gas and air. The furnace shown in Fig. 38 is for two melting holes, each capable of heating six crucibles.

The producer gas and air pass up through their respective chambers on each side, alternating during the melt, and produce a very satisfactory heating effect. As the melting hole across which the flame passes is very narrow, the gas and air combine and burn in the three narrow flues before entering the melting hole. The progress of the flame through the melting hole is also retarded by having the three inlet ports out of line with the three outlet ports on the opposite side of the melting chamber. A very intense heat is obtained in this manner, so much so that the cutting action of the flame upon the sides of the melting hole is most severe, necessitating the use of protecting bricks, which are made of the highest resisting silica firebrick. The form of the melting hole also encourages the concentration of the heat; the inclination of the brickwork on each side of the chamber towards the top deflects the heat upon the crucibles.

The crucibles stand on coke dust, which forms the bottom of the melting hole. At the bottom of the coke bed and in the centre of the melting chamber, there is a hole which passes right through the brick and iron work forming the bed, to a vault below. This hole is usually covered with an old crucible clay lid, upon which the coke dust rests. Should an accident happen and a charge of steel be lost, a hole is made through the coke bed to the vault below, and

the steel allowed to fall through. The coke bed is renewed and work proceeds again without much delay.

Operation of the Furnace.—As a rule, two shifts are employed in working this furnace, each gang obtaining three heats during the shift; the second gang

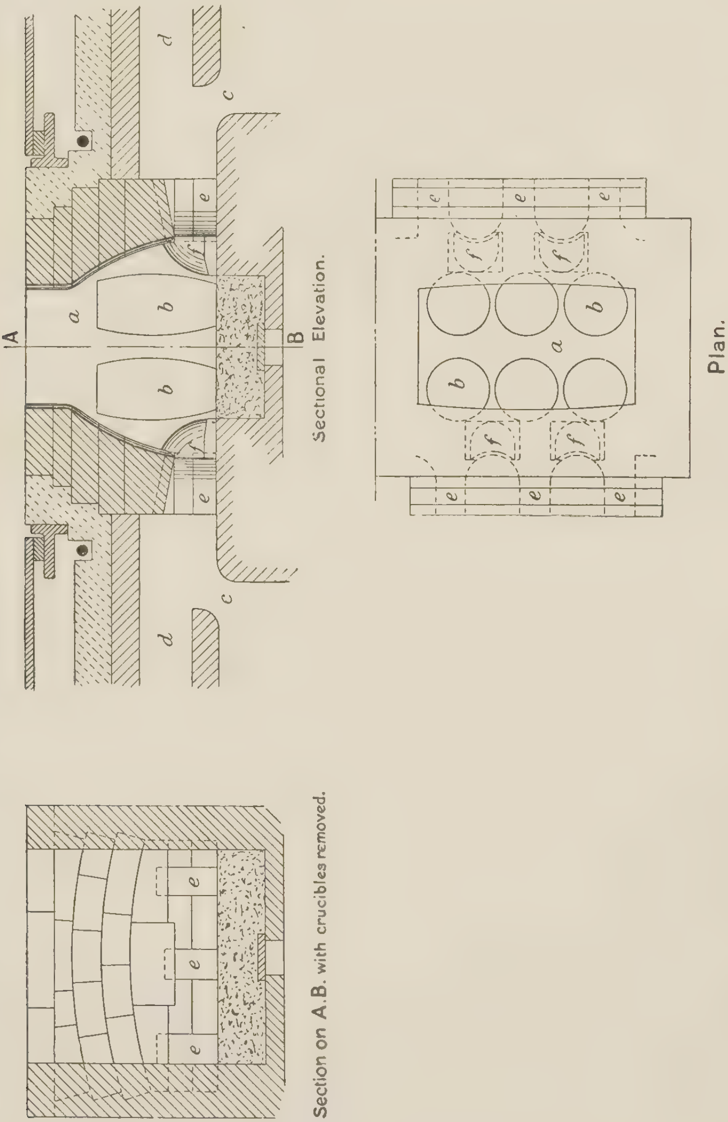


FIG. 39.—Details of Melting Hole of Siemens Gas-fired Crucible Furnace.

a, Melting hole; *b*, *b*, Crucibles; *c*, *c*, Gas ports; *d*, *d*, Air ports; *e*, *e*, Inlet and outlet ports of melting hole; *f*, *f*, Renewable refractory blocks for protecting brickwork around ports.

relieves the first after the third heat is completed, at whatever hour that may be. The furnace works continuously from Monday morning till Saturday morning, when it is patched or repaired if necessary. A hole through the coke bed in the melting chamber is usually made every Saturday, and any clinker and steel

from the furnace is pushed through the bottom, after which a fresh bed of coke dust is made.

Each melting chamber holds 6 crucibles, and is closed by 3 covers lined with firebrick. As each cover serves for 2 crucibles, it is unnecessary to move more than one at a time, when placing or removing the crucibles.

The handling of the crucibles in charging and pulling out does not differ from that in working the other crucible furnaces. The regulation of the gas and air is most important for producing uniform heating, which is sometimes very difficult to obtain throughout the melting hole without careful manipulation of the gas and air valves.

Output and Cost of the Furnace.—The installation of a plant to produce 25 tons of molten steel per week, or $4\frac{1}{2}$ tons per day of 24 hours for ordinary steel castings, is very costly compared with that of coke-fired crucible furnaces. If each chamber is capable of melting 6 heats in the 24 hours, and each crucible has an average capacity of 75 lbs., the weight of steel melted in that time = 2700 lbs. per chamber. To produce $4\frac{1}{2}$ tons per 24 hours, it would be necessary to have 4 melting holes.

One complete furnace, with four melting holes, having regenerators on each side could be installed, or two separate furnaces each having two melting holes. The latter proposition would be better, inasmuch as the melter would thereby obtain more uniform results in heating. This consideration alone would be sufficient to induce one to instal two blocks. Fig. 38, previously referred to, is an illustration of one pair of melting holes.

The cost of two complete double melting hole furnaces, including gas producers and chimney, would be approximately £3500.

∴ Annual charge for depreciation @ 10% = £350
„ „ interest @ 5% = £175

Total charge . . . £525.

Charge for depreciation and interest per ton of steel melted $= \frac{525 \times 20}{1200} =$ 8*s.* 9*d.*

Working Costs (per ton of Liquid Steel for Carbon Steel Castings)

Cost of Repairs.—With reference to the repairs to the furnace, these vary in some measure according to the method of working. Irregular heating not only affects the crucibles and the output of steel, but the walls and ports of the furnace as well. Gas furnaces of the type illustrated can run continuously for about 6 months without repairs, except for the usual week-end renewals of coke beds, etc. A fortnight to 3 weeks is required for the dismantling, rebuilding, and reheating, and the cost depends upon the extent of the work done.

The total cost of repairs per ton of steel, including repairs to furnace, producers, and making good coke bottom weekly, = on an average 6*s.* 6*d.* per ton.

Cost of Fuel.—Instead of using expensive coke at anything between 20*s.* and 30*s.* per ton, an inferior coal can be used in these furnaces at a cost of 7*s.* to 10*s.* per ton in the Sheffield district. The average amount of coal consumed for melting ordinary steel for castings is about $1\frac{1}{2}$ tons which, with coal at 10*s.* per ton, makes the cost of fuel per ton of steel melted = 15*s.*

Cost of Crucibles.—When gas furnaces were introduced to Sheffield, Messrs. Samuel Osborn and Co., Ltd., who were about the first to instal one, found it difficult to maintain an uniform temperature throughout the melting chamber, which caused some of the crucibles to get too hot and fail, whilst others were

not sufficiently heated. This danger is now overcome, and by regular reversals of the gas at each side of the furnace, an even temperature is obtained throughout. When melting materials for tool steel, an average of 3 to 4 heats are obtained per clay crucible, and from 8 to 12 heats from good plumbago crucibles. By melting steel scrap, etc., for mild steel castings in clay crucibles, from 3 to 5 heats can be obtained from each crucible, while plumbago crucibles give an average of about 15 heats. When producing steel for castings in plumbago crucibles of an average capacity of 75 lbs., each crucible will melt 1125 lbs. of steel, therefore the approximate cost of plumbago crucibles per ton of steel melted, when crucibles cost 9*s.* 6*d.* each, = 19*s.*

Cost of Labour.—The following men are employed per shift:—

	Day Shift.			Night Shift.		
	£	*s.*	*d.*	£	*s.*	*d.*
One gas producer man	0	5	0	0	6	6
,, melter	0	7	6	0	9	0
Two pullers-out @ 6*s.* 6*d.* each	0	13	0	0	15	0
Three labourers @ 5*s.* each	0	15	0	0	18	0
Total	£2	0	6	£2	8	6

Working 11 shifts per week, the total weekly wages = £24 5*s.* 6*d.*

Adding 100 per cent. for part expenses of foremen, chemist and management, the total cost per week = £48 11*s.* 0*d.*

$$\therefore \text{ Cost of labour per ton of steel melted} = \frac{£48\ 11s.\ 0d.}{25} = £1\ 18s.\ 10d.$$

Cost of Raw Materials.—The cost of raw materials is taken at £4 2*s.* 11*d.* as in the other estimates.

Summary of Costs.

Cost of furnace, £3500.

	£	*s.*	*d.*
Depreciation and interest	0	8	9
Repairs	0	6	6
Fuel	0	15	0
Crucibles (plumbago)	0	19	0
Labour	1	18	10
Raw materials (including additions and loss)	4	2	11
Total cost per ton of liquid steel	£8	11	0

"New-Form" Siemens Furnace

Description of the Furnace.—The construction of this furnace is shown in Fig. 40. The chief points of difference between the "ordinary-form" and "new-form" of Siemens crucible furnaces are as follows:—

(1) One pair of regenerators is used instead of two. The gas from the producer passes direct to the melting chambers instead of through regenerators, and meets the heated air drawn through the air regenerator, mixing with it before actually reaching the melting chambers.

(2) The arrangement of the producer makes it virtually part of the same structure as the furnace, and not a separate part as in the older form of furnace. The gas is thereby delivered to the melting chamber at the initial temperature of the gas producer. A considerable saving in fuel is thereby effected, as losses in

transmission are avoided, such as those arising from (*a*) the deposit of tar and soot in the flues between the producer and the furnace (the useful heat from which is utilised in the "new-form"); (*b*) the loss of gas at each reversal of the the gas valve, and also the inevitable escape of gas through imperfectly fitting valves; and (*c*) losses due to radiation from the external parts of producer and flues.

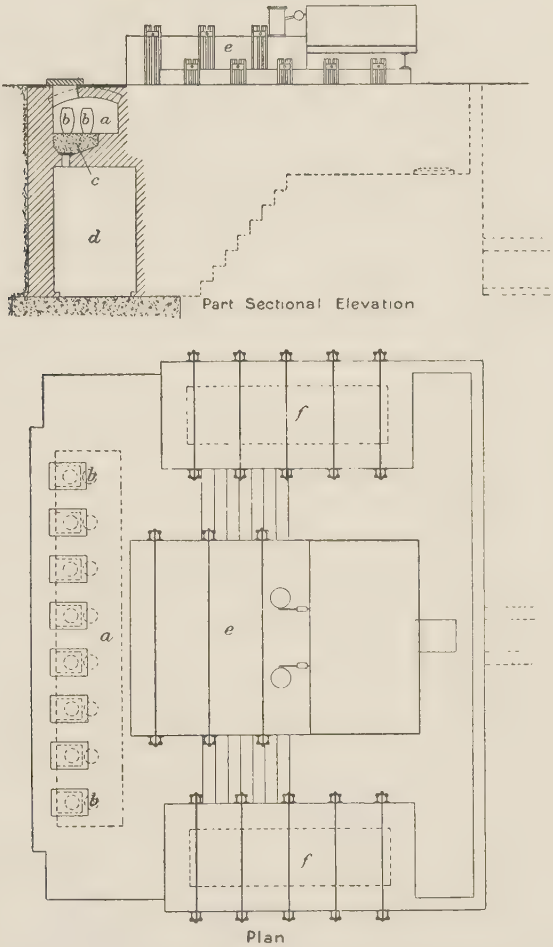


FIG. 40.—"New-Form" Siemens Gas-fired Crucible Furnace.

a, Melting chamber; *b*, *b*, Crucibles; *c*, Coke bed; *d*, Vault; *e*, Gas producer; *f*, *f*, Air regenerators.

(3) Another point of difference, and one which should appeal to manufacturers, is the initial cost of the furnace, which is between 30 per cent. and 50 per cent. less than that of the "ordinary-form" Siemens. It also occupies less space, a factor of considerable importance where ground area is limited and valuable.

The size of the melting chamber for a furnace in which 12 crucibles are heated is about 16′ × 4′. The flame from the mixture of gas and air enters at

one end and passes along the full length of the chamber, thence to the regenerator. The crucibles nearest the admission port are heated rather more quickly than those at the extreme end as long as the gas continues in the one direction, but the direction is reversed every 20 minutes, and what was formerly the inlet becomes the outlet. A proper regulation of the heat throughout the furnace is therefore maintained. The heat from the hot gases passing into each regenerator alternately, is absorbed by the chequer bricks before the spent gases enter the chimney. The regulation of the air admission to the regenerators is done by means of reversing valves, through which air at one time passes to the regenerators on the left-hand side, while the other on the right-hand side is open to the chimney. The melting chamber has a coke bed on which the crucibles rest, and is arched over at the top. There are 6 holes in the arch of a 12-pot furnace through which access is obtained to the melting chamber for charging and pulling out crucibles; suitable covers close the holes. Below the melting chamber a cellar of the usual form runs from end to end, communication to which is made by steps at each end.

Operation of the Furnace.—When a new furnace is built, the drying of the brickwork is carried out carefully. The brickwork is allowed to dry by natural draught for a day or two, afterwards a gentle fire of wood and then coke is introduced in the producer and melting chamber. The slower the drying the less chance there is of expansion. When the furnace is properly dried, the coal staging adjoining the producer is charged, and coal is fed into the producer through the hoppers. When the producer is fully charged, a steam jet can be turned on and the gas forced through the furnace. The rate of flow of gas is under perfect control, being regulated by a small steam valve, and the direction of the flame is changed at intervals by moving the gas and air reversing valves. The crucibles are usually placed in the melting chamber before being charged, and are then filled with steel scrap and pig iron through funnel-shaped fillers which rest on the crucibles. In some works the charging is done before the crucibles are placed in the melting chamber. The operation of melting is watched carefully by the melter and an examination made from time to time during the melt, which takes about 3 hours.

Output and Cost of the Furnace.—With ordinary crucible steels, 4 heats can be made in the 12-hour shift, but in England an average number of 3 heats is preferred during one shift, or 32 heats during one week's continuous operation of the furnace from Monday until Saturday morning. Using crucibles of 75 lbs. average capacity, the total weekly output from a furnace taking 12 crucibles would be $\frac{32 \times 12 \times 75}{2240} = 12\frac{1}{2}$ tons approx.

To obtain 25 tons output per week regularly, or 1200 tons per year of 48 working weeks, two such furnaces would be required, costing approximately £2000, but depending somewhat on the condition of the site upon which they were to be built. This price would include cost of furnaces with producers, chimney and foundations.

Annual charge for depreciation	@ 10% on 2000£ =	£200
" " interest	@ 5% on £2000 =	£100
Total charge . . .		£300

Charge for depreciation and interest per ton of steel melted $= \frac{300 \times 20}{1200} = 5s.$

Working Costs (per ton of Liquid Steel for Carbon Steel Castings)

Cost of Repairs.—The fact that the furnace can run for 12 to 18 months without requiring to be overhauled and the melting chambers and gas and air ports rebuilt, considerably limits the cost of repairs, which is smaller than with the ordinary Siemens furnace. The average cost is about 4*s.* 6*d.* per ton of steel melted. There is also the cost of renewing the coke bed weekly, and cleaning the producer, etc., which amounts to about 1*s.* per ton of steel melted. Total cost of repairs per ton of steel therefore = 5*s.* 6*d.* approx.

Cost of Fuel.—There is a very considerable saving in the cost of fuel compared with that consumed in the ordinary coke furnace. When the price of coal is 10*s.* per ton, one ton of steel can be melted in the "new-form" Siemens furnace for about 12*s.*

Cost of Crucibles.—An average of about 15 heats can be obtained from good plumbago crucibles, when melting mild steel scrap and pig iron for steel castings. At a price of 9*s.* 6*d.* each the cost of crucibles per ton of steel = approx. 19*s.* (If clay crucibles are used, an average of 4 heats can be obtained working on the same materials as above, or an equivalent of 300 lbs. of steel from one crucible. If taken at the price of 2*s.* each, the cost per ton of molten steel = approximately 15*s.*)

Cost of Labour.—This differs little from the labour on the ordinary gas-fired crucible furnaces, and is no more than is required for the coke-fired ones. Where two gas-fired furnaces of the size now being considered are installed, the labour involved in supplying coal to the gas producers would not be quite equal to that in wheeling coke to coke-fired furnaces, and at least one man less per shift would be required on this account. The labour required to work the two furnaces per shift is as follows:—

One melter.
Two "pullers-out."
Three labourers (one attends to gas producer).

Including part expenses of foremen, chemist and management, the cost of labour per ton of steel melted = approximately £1 16*s.* 9*d.*

Cost of Raw Materials.—This is taken at £4 2*s.* 11*d.* per ton, as estimated for the production of steel castings, and as used in the other costs.

Summary of Costs.

Cost of furnaces, £2000.

	£	*s.*	*d.*
Depreciation and interest	0	5	0
Repairs	0	5	6
Fuel	0	12	0
Crucibles (plumbago)	0	19	0
Labour	1	16	9
Raw materials (including additions and loss)	4	2	11
Total cost per ton of liquid steel	£8	1	2

"Ordinary" and "New-Form" Siemens Furnace Costs compared.

Details.	"Ordinary-Form" Siemens Furnace.	"New-Form" Siemens Furnace.
	£ s. d.	£ s. d.
Cost of furnace	3500 0 0	2000 0 0
Depreciation and interest @ 15%	0 8 9	0 5 0
Repairs	0 6 6	0 5 6
Fuel	0 15 0	0 12 0
Crucibles (plumbago)	0 19 0	0 19 0
Labour	1 18 10	1 16 9
Raw materials	4 2 11	4 2 11
Total cost per ton of steel melted	£8 11 0	£8 1 2

Dawson, Robinson and Pope Furnace

Description of the Furnace.—This furnace was designed with the object of obtaining better control of the gases in each melting hole than in the ordinary Siemens furnace. Fig. 41 shows the arrangement of the furnace, which consists of 3 separate melting holes built together in one block, behind which are two pairs of gas and air regenerators. The tops of the regenerators are below the bottom of the melting holes, the connection to each of the latter consisting of two gas and two air flues, which are under separate control.

In the sectional plan it will be observed that the flues are of different lengths. The gas and air pass through the two outer regenerators, along the flues to each of the three melting holes, and after sweeping round the furnace, pass along the two shorter flues to the two inner regenerators, thence to the chimney. The gases continue in this direction for 20 to 30 minutes, after which the gas and air valves are reversed, and the gas and air pass through the two inner regenerators, along the shorter flues to each melting hole, and return to the chimney by the longer flues and outer regenerators. The reversals of the direction of the gas and air are kept up at intervals while the furnace is in operation.

Operation of the Furnace.—No special knowledge is required to work this furnace, more than that required for working the ordinary gas-fired furnace. After the usual drying and heating has been carried out, the charging is performed in the customary manner. About 34 heats, and occasionally 36 heats, can be obtained from the furnace per week, when it is worked continuously from 6 a.m. on Monday until 9 a.m. on Saturday. Any repairs required to be done are carried out on the Saturday afternoon or during the week end. These are small, apart from the renewal of the coke beds at the bottom of the melting holes.

Each melting chamber holds 5 to 6 crucibles, and has three covers lined with firebrick of the usual type for closing the top of the furnace. These are removed singly as required, to admit of lifting 1 or 2 crucibles from the melting hole. The charging of the crucibles is performed after the crucibles are placed in the melting holes, the ordinary funnel being used for this purpose.

Output and Cost of the Furnace.—In melting ordinary crucible steel, an average output of 34 heats is obtained per week, working from 6 a.m. on Monday

until 9 a.m. on Saturday. Using crucibles of 75 lbs. capacity, the total weekly output from a furnace with 3 melting holes, each containing 5 crucibles is –

$$\frac{75 \times 34 \times 15}{2240} = 17 \text{ tons approximately.}$$

The cost of such a furnace without gas producer is roughly £900.

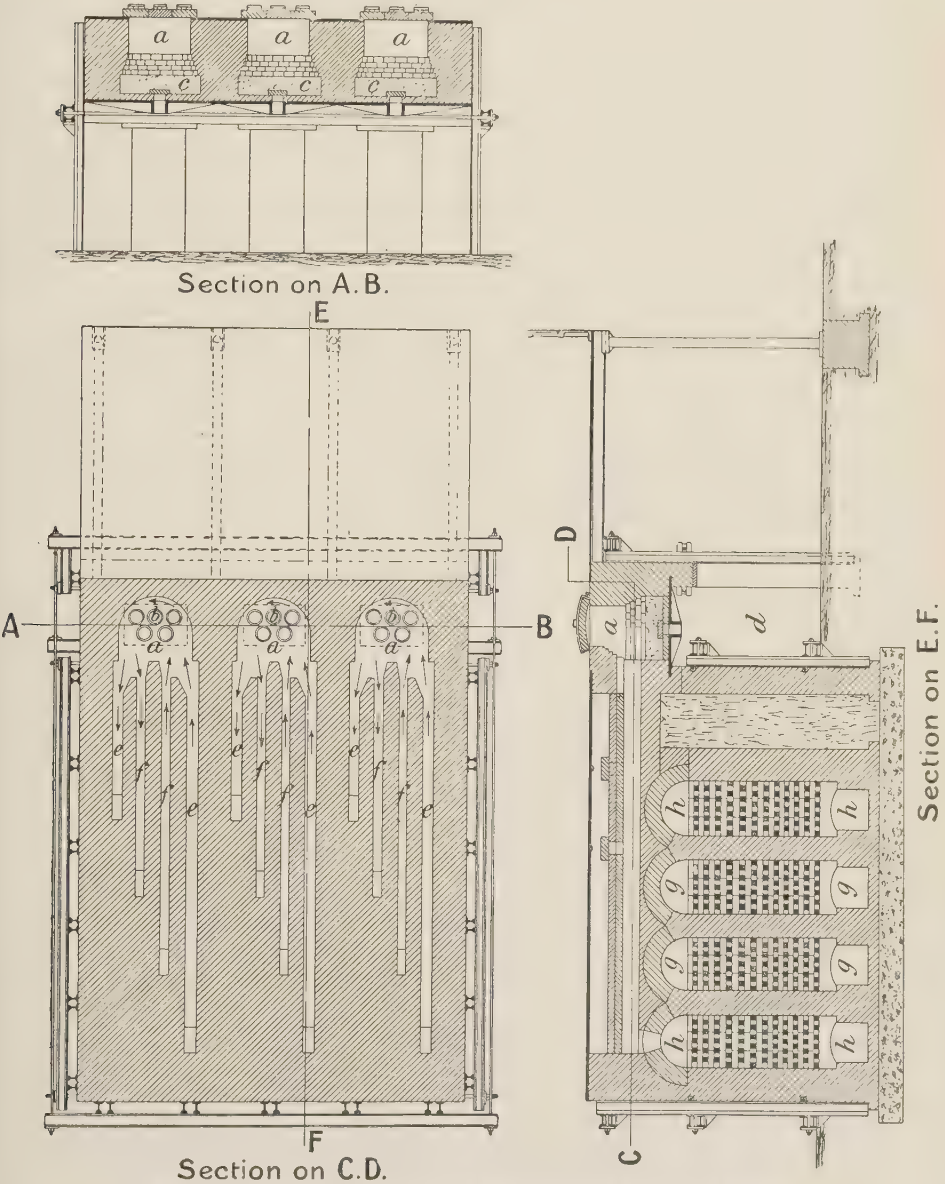


FIG. 41.—Dawson, Robinson, and Pope Gas-fired Crucible Furnace.
a, a, Melting holes; *b, b, b,* Crucibles; *c, c, c,* Coke beds; *d,* Vault; *e, e,* Air flues; *f, f,* Gas flues; *g, g,* Gas regenerators; *h, h,* Air regenerators.

To obtain 25 tons of steel weekly, a furnace with 5 melting holes would be necessary, costing approximately, with gas producer, chimney, valves, flues, and foundations, £2000.

$\therefore$ annual charge for depreciation @ 10 % = £200
" " interest @ 5 % = £100

Total charge £300

Charge for interest and depreciation per ton of steel melted—

$$= \frac{300 \times 20}{1200} = 5s.$$

Working Costs (per Ton of Liquid Steel for Carbon Steel Castings)

Cost of Repairs.—The weekly renewal of the coke beds is about all that is required during a 12 months' run of the furnace. The total annual repairs to furnace and producer, together with making good coke bottom weekly, are estimated at 5*s.* 6*d.* per ton of steel melted.

Cost of Fuel.—For melting tool and high-grade steels, the coal consumption varies from 27 to 35 cwts. per ton of steel melted, whereas for melting the same class of steel in the Huntsman furnace the coke consumption reaches 50 cwts. The coal consumption for the grade of steel now considered would be between 20 and 25 cwts. per ton of steel, and, taking the price of coal at 10*s.* per ton, the cost of coal is approximately 12*s.* per ton of steel melted.

Cost of Crucibles.—With proper care in handling, an average of 15 heats can be obtained from good plumbago crucibles when melting mild steel scrap and pig-iron for steel castings. The cost for crucibles, when taken at 9*s.* 6*d.* each, equals 19*s.* approximately per ton of steel melted.

Cost of Labour.—The following men are required per shift:—

	Day shift. £	s.	d.	Night shift. £	s.	d.
One gas-producer man	0	5	0	0	6	6
One melter	0	7	6	0	9	0
Two pullers-out @ 6*s.* 6*d.* each	0	13	0	0	15	0
Three labourers @ 5*s.* each	0	15	0	0	18	0
Total	£2	0	6	Total £2	8	6

Total weekly wages = £24 5*s.* 6*d.*

Adding 100 per cent. for part expenses of Foremen, Chemist, and Management, the total cost per week = £48 11*s.*

$\therefore$ Cost of labour per ton of steel melted $= \frac{£48\ 11s.}{25} = £1\ 18s.\ 10d.$

Cost of Raw Materials.—The cost of raw materials used in producing one ton of steel is taken at £4 2*s.* 11*d.*, as in the other estimates.

Summary of Costs.

Cost of furnace, £900.

	£	s.	d.
Depreciation and interest	0	5	0
Repairs	0	5	6
Fuel	0	12	0
Crucibles	0	19	0
Labour	1	18	10
Raw materials (including additions and loss)	4	2	11
Total cost per ton of liquid steel	£8	3	3

CHAPTER IX

CRUCIBLE STEEL FURNACES—AMERICAN PRACTICE

CRUCIBLE steel furnaces are used in America for melting materials for all kinds of small intricate steel castings which are found difficult and costly to produce by other methods of manufacture. They are also employed for the manufacture of steel for ordnance, such as small arms, guns, and projectiles; for various alloy steels, which are now used so much in high-class automobiles; and in the wearing parts of other machinery. It may be said, however, that crucible furnaces are mostly used for the manufacture of all classes of tool steel.

GAS-FIRED FURNACES

Different types of gas-fired furnaces are to be found in America, the one described and illustrated on p. 88 being not uncommon there. For larger plants, furnaces made to contain 30, 50, and 60 crucibles are also in regular operation, the following being a description of a typical 50-pot crucible furnace.

Description of the Furnace.—The melting chamber of the furnace containing 50 crucibles is divided into 8 compartments; each of the end compartments holds 8 crucibles, and 6 crucibles can be placed in each of the other 6 compartments. Although the furnace has capacity for 52 crucibles, only 50 are used at once, the remaining space being occupied for heating runner cups. The melting chamber is continuous but for the dividing arch at the top, which intercepts the flow of gas in its passage through the furnace. This is a useful baffle, and enables the gases to be spent more fully in the furnace instead of passing into the regenerator, and thence to the chimney. Every 20 minutes the direction of the gases is reversed, and a uniform temperature is maintained throughout the furnace. Each compartment is covered with frames lined with silica bricks. The end compartments have each four covers, one cover for 2 crucibles. The other compartments are each covered likewise, all being on the floor-level. There is a runway overhead in line with the furnace covers, from which is suspended a lifting-bar at the end of a chain. By the aid of this lifting-bar one man can remove and replace the covers from the top of the furnace. To one side of the melting hole are placed the ingot pits, and facilities are provided by a special tipping device for emptying the crucibles into them or into a ladle as required.

Operation of the Furnace.—The furnace works continuously from Monday morning until Saturday afternoon. The average number of heats is 6 every 24 hours, or 33 heats per week. It could be driven at a greater rate, but the effect on the furnace would be serious, and no economy obtained.

The materials for the charge are weighed in a room adjoining the furnace, and placed in small trays on light trucks, which are wheeled into the furnace house. While one man holds the crucible in a pair of tongs, another man

empties into it the contents of the tray through a filler cup placed over the mouth of the crucible. This is done carefully and quickly, the whole charge being well packed. The crucibles hold about 102 lbs., and are fitted with clay covers.

The melting proceeds in the ordinary way, taking from 3 to 4 hours per heat. When the heat is ready, one of the covers on the furnace is removed, exposing 2 crucibles only at a time. These are lifted out by hand-tongs, and handed to the teemer, who pours the contents into the ingot moulds or ladle. The crucible is immediately examined, and any slag removed before being passed on to the "fillers." No time is lost in the operation: each man knows his duty and carries it out with precision.

Output and Cost of the Furnace.—The cost of the furnace is estimated at £7000. The output is roughly 74 tons per week, or 3552 tons per year of 48 weeks. With such a large output, the charge per ton of steel melted for depreciation and interest is very much less than that of gas-fired furnaces working on smaller outputs.

Working Costs (per Ton of Liquid Steel for Carbon Steel Castings)

Cost of Repairs.—Howe[1] states that "American gas furnaces are repaired about every 6 months, with an outlay of about 350 dollars in the case of a 60-pot furnace." Apart from the weekly repairs, which consist of a small amount of patching and renewals of the coke bed, the practice and cost are now about the same as when Howe wrote on the subject. Sometimes a furnace will run for 9 months, but this is exceptional, the average time being 6 months.

The output of the furnace referred to by Howe was about 1600 tons during the campaign of 6 months, and the cost of repairs £72 18*s.* 4*d.*

∴ the cost of repairs per ton of steel melted = approximately 10*d.*

When the furnace is laid off for rebuilding, the time taken to do the repair is not more than 2 or three days as a rule, but the reheating of the furnace takes from 10 to 12 days. Silica bricks are used in rebuilding the melting chambers.

The cost of repairs given above is not comparable with the cost of gas-furnace repairs in Chapter VIII, which includes cost of making good the coke bottoms, and the weekly repairs to furnace and producer. The larger output of steel, however, from the American furnace in question brings down the cost of repairs per ton. By allowing 1*s.* 6*d.* per ton for weekly repairs, the total cost of repairs per ton of steel melted = 2*s.* 4*d.*

Cost of Fuel.—In large furnaces, the cost of fuel is less per ton than in small ones when melting the same class of material. The average consumption of coal at the producers per ton of steel melted in a furnace containing fifty 100-lb. crucibles is about 1200 lbs., but it has in some instances reached as low as 850 lbs.—a very remarkable figure for crucible furnace work.

Taking coal at 10*s.* per ton, which is below the average for some districts in America, the cost of fuel per ton of steel melted = approximately 5*s.* 6*d.*

The weight of slack coal consumed per 102 lbs. of iron melted in crucible gas-fired furnaces at Pittsburg[2] is given as 100 lbs., or approximately one ton of coal per ton of steel melted.

Cost of Crucibles.—Plumbago crucibles are commonly used in the States, costing 14*s.* each per 100 lbs. capacity. Before using them they are washed with silica paint inside to prevent the carbon from the plumbago crucible getting into the steel. About 7 heats are obtained from each crucible, or an equivalent of 700 lbs. of steel. Approximately 3·2 crucibles are required per ton of steel melted, at a cost of £2 4*s.* 10*d.*

[1] Howe, "Metallurgy of Steel," p. 302. [2] *Ibid.*, p. 310.

Cost of Labour.—The labour employed per shift on the furnace consists of the following :—

Three pullers-out.
Two teemers and fillers.
Two moulders.
One cover man.
One gas-producer man.
One coal wheeler.

Some of the men are employed on piecework, such as the pullers-out, who are paid $7\frac{2}{3}$ cents. ($3\frac{5}{6}d.$) per crucible lifted from the furnace. Other men are paid day work. They are employed by the head melter, who takes on the melting at a contract price per ton.

It is quite safe to take the average cost of labour, including part cost of management expenses and chemist, at £2 per ton of steel melted.

Cost of Raw Materials.—Assuming, for the sake of comparison, that the raw materials melted are of the same value as those used for ordinary castings, the cost per ton = £4 2*s.* 11*d.*

Summary of Costs.

Cost of furnace, £7000.

	£	*s.*	*d.*
Depreciation and interest	0	6	0
Repairs	0	2	4
Fuel	0	5	6
Crucibles	2	4	10
Labour	2	0	0
Raw materials (including additions and loss)	4	2	11
Approximate total cost per ton of liquid steel	£9	1	7

Oil-Fired Furnaces

The use of oil fuel and natural gas in crucible furnaces for melting steel has a distinct advantage over the use of coke in coke-fired furnaces, in that the oil fuel and natural gas do not impart sulphur to the steel during the process.

Description of the Furnaces.—There are several types of oil-fired crucible furnaces, some with a single chamber for holding one crucible and portable in form. Fig. 42 illustrates the type referred to. Fig. 43 shows a similar design, but arranged with the crucible fixed in the casing in such a manner as to allow of the casing being tilted without disturbing the crucible. These designs are more serviceable for metals having lower melting temperatures than steel, or for melting ferro-alloys used for "physicking" steels produced in larger quantities in other furnaces.

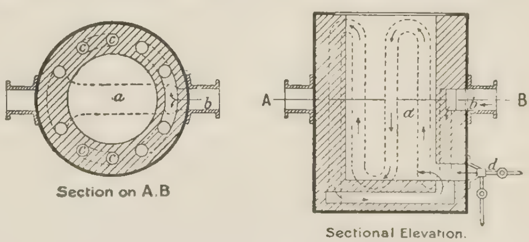


FIG. 42.—Tilting Oil-fired Crucible Furnace.

a, Melting hole; *b*, Air inlet; *c*, Air passage; *d*, Oil jet.

The first design of oil-fired furnace used in the United States is shown in Fig. 44, and is known as the Nobel furnace. Of the three separate chambers

shown, the first and second chambers were used for melting, and the third for heating the crucibles before use. It was found, however, that melting could not be satisfactorily carried out in the second chamber, which was therefore used for heating the crucibles only, the third chamber being used for observing the flame and working the furnace. The flue shown below the furnace was intended to carry the flame to the chimney instead of through the pot-holes during the operation of pulling-out. This was not very successfully effected, and is discarded in the modern oil-fired furnace.

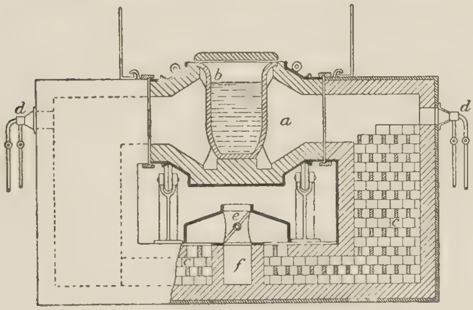


FIG. 43.—Tilting Oil-fired Crucible Furnace with Regenerators.

a, Tilting melting chamber; *b*, Crucible; *c*, *c*, Air regenerators; *d*, *d*, Oil jets; *e*, Reversing valve; *f*, Chimney flue.

The crucible furnace of the oil-fired type which competes with the coke and gas-fired furnaces in the production of steel for small castings is illustrated in Fig. 45. The chamber in which the crucibles are heated is rectangular in form, holding from 6 to 8 crucibles at one time. The design is simple, as the chamber, when covered, is virtually a box with an opening at each end near the bottom, the flame entering at one end and passing out at the other to the chimney. The inlet and outlet being at the bottom cause the flame to be directed to the bottoms of the crucibles, where the heat is most required.

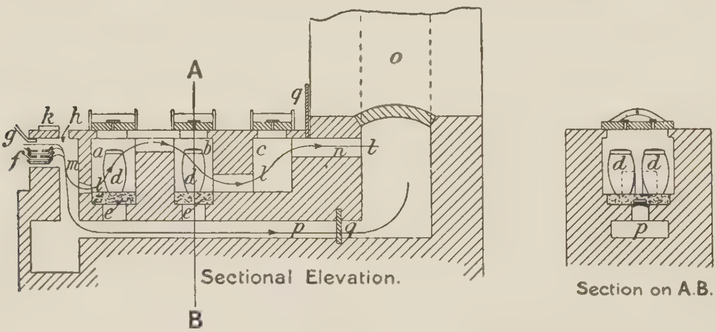


FIG. 44.—Nobel Liquid Fuel Crucible Furnace.

a, Melting chamber; *b*, Heating chamber; *c*, Examination chamber; *d*, *d*, Crucibles; *e*, *e*, Coke beds; *f*, Oil pans; *g*, Oil supply pipe; *h*, Air inlet; *k*, Air regulating cover; *l*, *l*, *l*, Direction of gases through furnace; *m*, Combustion chamber; *n*, Outlet flue; *o*, Chimney; *p*, Byepass flue; *q*, *q*, Dampers.

The flame is produced in a small combustion chamber, through the outer wall of which and near the top, oil and air are admitted. The oil is carried through small pipes to pans, which rest on shelves on the outer wall, between which the air passes into the combustion chamber. Provision is made for a further admission of air through the aperture on the top of the combustion chamber, the amount of which can be regulated by the brick tile on the top. Combustion does not always take place at first in the combustion chamber; it frequently happens that until the furnace is well heated combustion takes place in the chimney.

The bed of the furnace on which the crucibles are placed is made of old crucibles finely crushed and suitably mixed with ground coke. Trouble is sometimes experienced by the fusion of the bed on which the crucibles rest, causing them to stick to the bottom when ready for pulling out. After successive heats, however, the bottom becomes harder and less liable to unite with the crucibles.

Operation of the Furnace.—With the modern furnace just described, used for the manufacture of steel for castings, it is usual to work for 12 to 15 hours per day, allowing the furnace to rest during the night. This is rather severe upon the refractory material of which the chambers are built, owing to the expansion and contraction which take place. On account of this intermittent method of working the furnace, it is found more economical to use fireclay bricks instead of silica bricks for lining the chambers, as the latter would chip off more readily with the irregular temperatures to which they would be exposed.

The crucibles used for the first heat each day are placed in the furnace the previous evening, and about 3 a.m. the oil is turned on and the lighting in the pans commences. Between about 6.30 a.m. and 7 a.m. the four crucibles nearest the combustion chamber are ready for removal from the furnace. After removing the furnace cover, the crucibles are examined through a hole in the

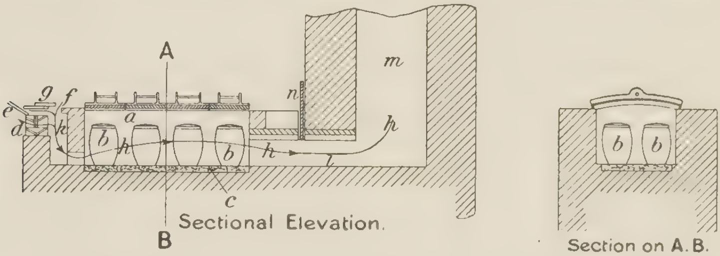


FIG. 45.—Improved Type of Nobel Liquid Fuel Crucible Furnace.

a, Melting chamber; *b*, *b*, Crucibles; *c*, Coke bed; *d*, Oil pans; *e*, Oil supply pipe; *f*, Air inlet; *g*, Air regulating cover; *h*, *h*, *h*, Direction of gases through furnace; *k*, Combustion chamber; *l*, Outlet flue; *m*, Chimney; *n*, Damper.

clay lid. If additions are necessary, these are added, before the crucibles are pulled from the furnace. The "pulling" is done in the ordinary way, after which the clay lid is removed, the metal skimmed, and a small piece of aluminium added to the steel, which performs the same functions as were obtained formerly by means of "killing." The amount of aluminium added is kept very low, to avoid any injurious results from its presence in the finished steel.

While the contents of the crucibles are being teemed into the moulds, the remaining 4 crucibles in the furnace are brought forward and replaced by other 4 all ready to be set in the melting chamber, and so the process of melting proceeds, until the furnace is stopped for repairs, which are required every 2 weeks. From 6 to 7 heats of 4 crucibles in each heat are obtained from the furnace in about 12 hours.

Output and Cost of the Furnace.—In the old type of furnace used at the Milwaukee Crucible Steel Foundry,[1] 14 charges of steel in crucibles containing 86 lbs. were melted per day, and in doing so 170 gallons of oil were consumed, equal to 316 gallons per ton of steel melted. In the modern furnace used in the same works, 24 crucibles of steel each containing 85 lbs. were melted

[1] "The Foundry," vol. xxxvi, p. 130.

with a consumption of 240 gallons of oil, or equal to 263 gallons per ton of steel melted. In the same town, a typical crucible foundry using the same type of crucible furnace, uses crucibles of a capacity of 176 lbs.[1]

Assuming the output of liquid steel required to be 25 tons per week, it would be necessary to instal 5 furnaces such as described and illustrated in Fig. 45, giving an output of $85 \times 4 \times 6 = 2040$ lbs. of steel per day per furnace, or $2040 \times 5 \times 6 =$ somewhat more than 25 tons of steel from the 5 furnaces per week of 6 working days. Each furnace would cost approximately £150, so that the total cost of the 5 furnaces, including the necessary chimneys, would be about £750.

Taking the usual depreciation of 10 per cent. and interest at 5 per cent. on the capital outlay :—

	£	s.	d.
Annual charge for depreciation @ 10% . . .	75	0	0
" " interest @ 5% . . .	37	10	0
Total charge . . .	£112	10	0

As the furnace is so often down for repairs, the actual time it is at work would not exceed 45 weeks in the year. The annual output would be therefore 1125 tons.

Charge for depreciation and interest per ton of steel melted

$$= \frac{£112\ 10s.}{1125} = 2s.$$

Working Costs (per Ton of Liquid Steel for Carbon Steel Castings)

Cost of Repairs.—Howe[2] states that a Nobel furnace runs probably about 18 days; the longest run at an American mill has been 27 days. Carl Smerling[3] says the average run of this type of furnace is 16 days, after which the side walls and arches have to be replaced.

The cost of rebuilding is about £8 after a 20 days' run, during which time 18 tons of steel were produced, so that the cost of repairs per ton of steel melted = approximately 9*s.*

Cost of Fuel.—This is a varying value, according to the market price of oil, but the consumption per ton of steel melted is fairly constant. Taking 263 gallons per ton at 2½*d.* per gallon, the cost of fuel is £2 14*s.* 10*d.* This price would appear almost prohibitive, but it is confirmed by Howe,[4] who states that 87 lbs. of petrol, at 5 cents per gallon, are used per 100 lbs. of steel melted in the crucible oil furnaces. This is equivalent to £2 16*s.* per ton of steel melted.

Heavy refuse oil, costing 2½ to 3 cents per gallon, has been tried, but owing to the production of a poorer flame and the oil carbonising in the pans, extra labour is required in keeping them clean, and a loss of 20 per cent. to 30 per cent. in fuel is experienced.

The cost of fuel per ton of steel melted will therefore be taken as £2 14*s.* 10*d.*

Cost of Crucibles.—The crucibles are subjected to very severe conditions. The rapid melting, compared with that in the gas-fired furnaces, hastens the destruction of the crucibles. In one of the Milwaukee steel foundries, 4 to 5

[1] "Giesserei-Zeitung," vol. vii, pp. 103–108.
[2] Howe, "Metallurgy of Steel," p. 302.
[3] "The Foundry," vol. 36, p. 130.
[4] Howe, "Metallurgy of Steel," p. 310.

heats are obtained from each plumbago crucible, "but in order to reach this record, they (the crucibles) must be daubed on the outside with a mixture of fireclay and powdered crucibles."[1] In other foundries in the same district, "crucibles withstand on an average 7 to 8 charges."[2] There is nothing extraordinary in these two statements, as the conditions of working, the composition of the charges, and the quality of the crucible all have an influence on the life of the crucible. Differences in the endurance of the life of crucibles for melting steel for castings in British foundries are just as great. Taking the average number of heats per crucible at 6, and the capacity of each at 85 lbs., the equivalent output in steel per crucible is $85 \times 6 = 510$ lbs. The number of crucibles therefore required per ton of steel = 4·4, and taking the crucibles at 12*s.* each, the cost of crucibles per ton of steel melted = £2 12*s.* 10*d.* approximately.

Cost of Labour.—The approximate number of men required is as follows:—

One teemer,
Three "pullers-out,"
Eight labourers.

The cost of labour varies considerably, and it is somewhat difficult to give reliable figures for each member of the gang. Including cost of supervision, chemist, and management charges, the cost of labour per ton of steel = approximately £2 2*s.*

Cost of Raw Materials.—The figure of £4 2*s.* 11*d.* per ton is taken as with the other furnaces, for the sake of comparison.

Summary of Costs.

Cost of furnaces, £750.

	£	*s.*	*d.*
Depreciation and interest	0	2	0
Repairs	0	9	0
Fuel	2	14	10
Crucibles	2	12	10
Labour	2	2	0
Raw materials (including additions and loss)	4	2	11
Total cost per ton of liquid steel	£12	3	7

[1] "The Foundry," vol. 36, pp. 130–132.
[2] "Giesserei-Zeitung," vol. vii, p. 103.

CHAPTER X

COST OF CRUCIBLE STEEL FOR CARBON AND HIGH-SPEED TOOLS

STEEL for carbon and high-speed cutting tools can be melted in any of the furnaces described in the chapters in this section on crucible steel manufacture. It is perhaps more common, at least in this country, to melt these classes of steel in coke-fired furnaces, although less sulphur is imparted to the steel when gas-fired furnaces are used, and this is a most important consideration in making high quality steels.

Many users of coke-fired furnaces prefer them to the gas-fired furnaces because they can make small quantities of steel of as many different "tempers" or classes as they have melting holes, whereas the number of qualities which can be produced at a time with the gas-fired furnace is more limited, since usually these furnaces have 5 or 6 crucibles at least in one melting hole, while some furnaces have as many as 50 or 60 crucibles in one chamber.

In melting charges for tool steels, crucibles of smaller capacities are used as a rule, and the time required for melting and finishing is more than that taken in melting ordinary mild steel scrap and pig iron charges.

Operation of the Furnace.—In making tool steels, no alteration is necessary in the operation of the furnace as when used for producing ordinary steel. More care, however, is required in charging coke and in handling the crucibles to prevent any possible chance of losing a charge.

Output and Cost of the Furnace.—The average capacity of crucibles used for melting steel for carbon and high-speed tools is about 55 lbs., and in the ordinary Huntsman type of furnace, two crucibles only are use in each melting hole, yielding 110 lbs. of steel per heat. To produce 25 tons of steel per week, working continuously from Monday morning to Saturday morning, 16 melting holes would be required, each melting 3 heats per shift, or 33 heats per week.

The approximate cost of furnace would be £1200.

Annual charge for depreciation,	10 % on £1200	=	£120
" " interest,	5 % on £1200	=	60
Total charge . . .		=	£180

∴ Charge for depreciation and interest per ton of steel melted

$$= \frac{180 \times 20}{1200} = 3s.$$

WORKING COSTS (PER TON OF LIQUID STEEL)

Cost of Repairs.—The annual cost of repairs per ton of steel melted in a Huntsman furnace with 16 melting holes is approximately 4*s*. 9*d*. per ton. This

includes cost of labour and refractory materials used in relining the melting holes every few weeks, and rebuilding arches and flues when the general repair is carried out annually.

Cost of Fuel.—It is necessary to use the best washed coke, as free from sulphur as possible, so that the steel melted may be kept free from contamination. Sulphur finds its way into the steel even when the crucible is closed with a fireclay lid, hence the necessity for pure fuel.

The average time of melting and finishing each heat is longer than that required for ordinary steel, and as the charge in each crucible is less, more coke per ton of steel is required.

According to the grade of steel melted, $2\frac{1}{2}$ to $3\frac{1}{2}$ tons of coke are required per ton of steel. Taking the amount of coke required for the production of carbon tool steel at 3 tons per ton of steel, and using coke at 28*s.* per ton, the cost of fuel per ton of carbon tool steel = £4 4*s.* For high-speed tool steel, about $3\frac{1}{2}$ tons of coke are required per ton of steel. Therefore cost of fuel per ton of high-speed steel = £4 18*s.*

Cost of Crucibles.—Wherever good clay crucibles can be made it is usual to employ them for melting materials for carbon tool steels and high-speed tool steels. They can be made by experienced men, and most works find their use more economical than plumbago crucibles for these classes of steels. They do not last more than 3 heats as a rule (the 3 heats giving about 70, 56, and 40 lbs. of steel respectively), but they only cost 1*s.* to 2*s.* each to produce if made with modern appliances.

Taking the price of 1*s.* each crucible, the cost per ton of steel melted

$$= \frac{2240 \times 1}{55 \times 3} = 13s.\ 6d.$$

Cost of Labour.—The number of hands employed and the wages paid are as follows :—

	Day shift. £ s. d.	Night shift. £ s. d.
One melter	0 7 6	0 9 0
Three pullers-out @ 6*s.* 6*d.* each .	0 19 6	1 2 6
Three coke wheelers @ 5*s.*	0 15 0	0 18 0
One labourer	0 5 0	0 6 0
One cellar lad	0 3 0	0 3 6
Total . .	£2 10 0	Total £2 19 0

Working 6 day and 5 night shifts, the total weekly wages = £29 15*s.*

Adding 100 per cent. as part expenses for foremen, chemist, and management = £29 15*s.*, the total cost of labour per week = £59 10*s.*

$\therefore$ Cost of labour per ton of liquid steel $= \frac{£59\ 10s.}{25} = £2\ 7s.\ 7d.$

Cost of Raw Materials.—It is under this heading that the cost of production is more variable than in any other item of cost. There are so many varieties of alloy steels used for high-speed tools, and the materials are so expensive that the cost of a special alloy steel is sometimes 4 to 8 times that of ordinary carbon steel for cutting tools.

Tool steel may be divided into two distinct classes :—

1. Carbon steels.
2. Alloy steels.

The raw materials used in each class are as free as possible from sulphur and phosphorus, and only very small additions of ferro-alloys are made to class (1) tool steels, along with suitable amounts of aluminium to clean and finish the liquid steel. In class (2) tool steels, comparatively large percentages of expensive alloys form part of the charge, hence the great cost of the finished steel.

The following charges are typical only and are subject to considerable variation, as will be observed from the study of the various charges and analyses of carbon and high-speed steels given in Chapter XI, dealing with the materials used in crucible steel manufacture.

1. *Carbon Tool Steel.*

Charge per 100 lbs. of liquid steel produced :—

	£	s.	d.
60 lbs. best Swedish bar iron (cut) @ 13*s*. cwt. . . .	0	7	0
42 lbs. „ carbon tool steel scrap @ 10*s*. cwt. . . .	0	3	9
Ferro-silicon, aluminium, and carbon additions according to temper of steel required	0	1	0
Cost per 100 lbs. of liquid steel . .	£0	11	9

∴ Approximate cost of raw materials per ton of liquid steel = £13 3*s*. 3*d*.

2. (*a*) *High-speed Tool Steel*

Charge per 100 lbs. of liquid steel produced :—

	£	s.	d.
82 lbs. best Swedish bar iron bar (cut) @ 13*s*. cwt.	0	9	6
13 lbs. tungsten powder (96 to 98 % tungsten) @ 2*s*. 9½*d*. lb. .	1	16	3½
5 lbs. ferro-chrome (60 % chrome) @ 19*s*. cwt.	0	0	10
4 lbs. ferro-molybdenum (80 % Mo) @ 5*s*. lb.	1	0	0
Cost per 100 lbs. of liquid steel . .	£3	6	7½

∴ Approximate cost of raw materials per ton of liquid steel = £74 12*s*. 5*d*.

2. (*b*) *High-speed Tool Steel*

Charge per 100 lbs. of liquid steel produced :—

	£	s.	d.
75 lbs. best Swedish bar iron (cut) @ 13*s*. cwt.	0	8	8
18·5 lbs. tungsten powder (96 to 98 % tungsten) @ 2*s*. 9½*d*. lb.	2	11	7
1 lb. ferro-vanadium (35 to 40 % V) @ 17*s*. 6*d*. per lb. of V .	0	6	0
8 lbs. ferro-chrome (60 % chrome) @ 19*s*. cwt.	0	1	4
Cost per 100 lbs. of liquid steel . .	£3	7	7

∴ Approximate cost of raw materials per ton of liquid steel = £75 13*s*. 11*d*.

2. (*c*) *High-speed Tool Steel*

Charge per 100 lbs. of liquid steel produced :—

	£	s.	d.
55 lbs. best Swedish bar iron (cut) @ 13*s*. cwt.	0	6	5
26 lbs. tungsten powder (96 to 98 % tungsten) @ 2*s*. 9½*d*. lb.	3	12	7
12 lbs. ferro-chrome (60 % chrome) @ 19*s*. cwt.	0	2	0
9·5 lbs. ferro-molybdenum (80% Mo) @ 5*s*. lb.	2	7	6
1 lb. ferro-vanadium (35 to 40 % V) @ 17*s*. 6*d*. per lb. of V	0	6	0
Cost per 100 lbs. of liquid steel	£6	14	6

∴ Approximate cost of raw materials per ton of liquid steel
= £150 12*s*. 10*d*.

Summary of Costs

	Carbon Tool Steel.			High-speed Tool Steels.								
	1.			2 (*a*)			2 (*b*)			2 (*c*)		
	£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.
Depreciation and interest	0	3	0	0	3	0	0	3	0	0	3	0
Repairs	0	4	9	0	4	9	0	4	9	0	4	9
Fuel	4	4	0	4	18	0	4	18	0	4	18	0
Crucibles (clay)	0	13	6	0	13	6	0	13	6	0	13	6
Labour	2	7	7	2	7	7	2	7	7	2	7	7
Raw materials	13	3	3	74	12	5	75	13	11	150	12	10
Cost per ton of liquid steel	£20	16	1	£82	19	3	£84	0	9	£158	19	8

As already remarked, the charges are subject to considerable variations, but the above prices give some idea of the ultimate cost of a finished bar of tool steel when it is remembered that only a part of each ingot cast is used, and that very often losses arise in the various processes through which the steel must pass before it reaches the warehouse.

CHAPTER XI

COMPOSITION OF CHARGES EMPLOYED AND ANALYSES AND USES OF STEEL PRODUCED IN THE CRUCIBLE PROCESS

Uses of Crucible Steel.—Before giving the charges and analyses of steel used in this process, it is perhaps advisable to outline the extent of the use of crucible steel. It is difficult to give a comprehensive list of the uses of steel made in the crucible furnace only, as steel is produced in the other processes (Bessemer, Open-hearth, and Electric) for some of the purposes for which crucible steel is used. In fact, before the Bessemer and Open-hearth processes were introduced, and for some years afterwards, steel ingots for heavy work such as engine cranks, pistons, piston rods, connecting rods, axles for engines, as well as the component parts of locomotives and other engines and rolling stock, were made from crucible steel. To this day, Messrs. F. Krupp, at Essen, employ the crucible process for the manufacture of steel for guns and other warlike materials, the ingots for which sometimes weigh 80 tons.

The following list gives some of the articles which are usually made by the crucible process of to-day :—

Ingots for—

- Cutting tools of all kinds, such as the tools used in engineering establishments for cutting steel, iron, brass, and other alloys.
- Cutting tools for mines—chisels, bits, drills, etc., for minerals.
- Cutting tools, such as cutlery of all kinds for home use, wood-working tools, and various manufacturing uses.
- Dies for coining, stamping cutlery, all kinds of sheet metal work, tubes, and for the various classes of manufactures, too numerous to mention.
- Files and springs, hammers, shearing blades, milling cutters, agricultural tools.
- Ordnance and Artillery, small arms, guns, projectiles, etc.
- Shafts, spindles, rods, axles, and other wearing parts of all kinds of small and intricate machines.

Castings for—

- Small and intricate parts of machines used in all kinds of manufacture, for rolling stock, automobiles, and flying machines.
- Also in commoner grades of machines and parts of machines used for railway, colliery, mining, hydraulic, and marine engineering.

Materials used in the Charges.—Crucible steel charges are perhaps more varied in composition than the uses to which steel from this process is employed. It is a common saying that one need only expect to get from the crucible, steel of a quality equal to that contained in the materials used for melting, the process being virtually one of melting only. This, however, is not strictly accurate, as the elimination of impurities by oxidation takes place to some extent in this

process as in the other methods of manufacture, although to a much lesser degree.

The manufacture of steel by the crucible process demands the greatest care and skill to produce material with a final carbon content which will be most suitable for the purposes required. Mr. Seebohm,[1] in his paper on crucible steel, gives a classified list of uses of carbon steels with carbon varying from 1·5 per cent. (razor temper) to 0·75 per cent. (die temper).

Mr. J. M. Gledhill[2] gives the following list of tools which he considers will give the best results when containing the following percentages of carbon :—

Carbon 1·3 per cent.—
Small planing and turning tools, drills and cutters, razors and surgical instruments.

Carbon 1·15 per cent.—
Heavier turning, planing, and slotting tools, drills, cutters, reamers, and engineering tools.

Carbon 0·9 per cent.—
Large circular cutters; reamers, taps, screwing dies, heavy turning tools, large drills, and taps.

Carbon 0·8 per cent.—
Cold chisels, hot setts, small shear blades, and large taps.

Carbon 0·75 per cent.—
Screwing dies, cold setts, hammers, swages, minting dies, miners' drills, smiths' tools, punches, and shear blades.

Carbon 0·65 per cent.—
Suitable for snaps, dies, cup drifts, hammers, and stamping dies.

Tool Steel Charges and Analyses.—The best tool steels are usually made from specially selected blister steel, produced by the cementation of the best quality bar iron. For many years nothing but this material was used for all kinds of crucible steel manufacture. Subsequently it was found necessary, with the advent of other processes and competition, to employ cheaper raw materials, such as puddled bar iron, containing sufficient carbon to give the desired results in the finished steel. At a still later stage, steel from open-hearth furnaces and Bessemer converters has been used in the manufacture of some classes of tool and other steels. Sir Henry Bessemer stated[3] in 1884, that at least one-half of the crucible steel in Sheffield was then made from Bessemer and Siemens' scrap, simply remelted.

At Kapfenberg,[4] the principal centre of crucible steel manufacture in the Austrian Alpine region, the basis of manufacture is the charcoal pig iron of Eisenerz and Vordernberg, smelted from Spathic ores of the Styrian Erzberg, which vary in composition and produce the following percentage analyses of pig iron :—

	1.	2.
Carbon	3·5	4·20
Silicon	0·11	0·24
Manganese	0·8	2·40
Phosphorus	0·03	0·07
Sulphur	—	0·02
Copper	—	0·005

The puddled steel made from the pig iron is converted into bars by rolling. These bars are hardened and broken for sorting before being melted in the

[1] "Journal Iron and Steel Institute," 1884, II.
[2] "Engineering Review," 1904, p. 405.
[3] "Journal Iron and Steel Institute," 1884, II, p. 373.
[4] "Proceedings Institution of Civil Engineers," vol. cxxii, p. 470.

crucible. It is stated by A. Ledebur, that as a result of a long-continued series of experiments, the addition of mild steel—either Bessemer or open-hearth, to the crucible charges, has been abandoned. This, of course, refers to the manufacture of tool steel.

The almost universal practice in America, says Campbell,[1] is to put charcoal into the crucible with the bar iron, the absorption of carbon progressing with rapidity when the metal is fluid.

There can be no doubt, however, that the practice followed by most Sheffield manufacturers of using blister steel made from bar iron by what is known as the Swedish Lancashire hearth or Walloon process from the practically pure pig iron made from Dannemora and Persberg iron ores, has earned for them a reputation which is world-wide. The analysis of Swedish bar iron[2] before being cemented, is as follows:—

C	Si	Mn	P	S
0·04	0·02	0·13	0·01	0·016 per cent.

Self-Hardening and High-Speed Steels.—Mr. Robert Mushet discovered that tungsten, added to ordinary carbon steel, produced the remarkable properties of self-hardening.

Becker[3] gives the composition of the original self-hardening steel which was known as "R. Mushet's Special," as follows:—

Carbon	2·0%
Tungsten	5·0%
Chromium	0·5%
Manganese	2·5%
Silicon	1·3%

and the same author gives the following average percentage analyses in Table XLVII of 20 brands of self-hardening steels and 20 brands of good high-speed steels:—

TABLE XLVII

ANALYSES OF HIGH-SPEED TOOL STEELS

Constituents.	Self-hardening.			High-speed.			Recommended by Taylor as best all-round cutting steel.	
	Average.	High.	Low.	Average.	High.	Low.	1.	2.
Carbon	1·8	2·4	1·1	0·75	1·28	0·32	0·682	0·674
Tungsten	7·3	11·6	4·5	18·0	25·45	17·81	17·81	18·19
Molybdenum	4·58	—	—	3·5	7·6	0·00	—	—
Chromium	1·6	3·4	0·07	4·0	7·2	2·23	5·95	5·47
Vanadium	—	—	—	0·3	0·32	0·00	0·32	0·29
Manganese	1·8	3·5	0·08	0·13	0·30	0·03	0·07	0·11
Silicon	0·56	1·04	0·16	0·22	1·34	0·43	0·049	0·043
Phosphorus	0·032	0·08	0·016	0·018	0·029	0·013	—	—
Sulphur	0·015	0·05	0·004	0·01	0·016	0·008	—	—

[1] Campbell, "The Manufacture and Properties of Iron and Steel," p. 94.
[2] "Journal Iron and Steel Institute," 1908, II, p. 105
[3] Becker, "High Speed Steel," p. 46.

H. Le Chatelier[1] gives the following as an average constitution for a rapid tool steel :—

Iron	83·0%
Tungsten	12·0%
Chromium	3·0%
Molybdenum	1·0%
Carbon	0·5%
Silicon	0·2%
Manganese	0·2%

The percentages of phosphorus and sulphur are not given, but it is well known that both elements should not exceed 0·02 per cent., although it has been found in analysing some high-speed steels that the phosphorus and sulphur contents have exceeded 0·05 per cent.

Below is a table of Tungsten steels made in England, France, and Austria :—

TABLE XLVIII

Percentage Analyses of Tungsten Steels

	W	C	Si	Mn	P	S
Schneider (France)	11·03	2·15	0·26	1·49	·007	—
Mushet (S. Osborn and Co., Ltd., Sheffield)	9·99	1·24	0·33	1·04	·04	—
Other English make	6·73	2·06	0·05	2·66	—	—
Styrian	6·45	1·2	0·21	0·85	—	—

Molybdenum-chrome steels, having the following analyses, gave very satisfactory results :—

	(1)	(2)	(3)	
Carbon	0·96	0·85	0·86	per cent.
Molybdenum	3·2	3·02	3·75	„
Chromium	3·0	2·95	3·75	„

High-Speed Steel Charges.—The following charges of materials for producing high-speed steel are typical :—

(1) To produce 100 lbs. of tool steel.

Best Swedish bar iron (cut)	82 lbs.
Tungsten powder (96 to 98% W)	13 lbs.
Ferro-chrome (60% Cr)	5 lbs.
Ferro-molybdenum (80% Mo)	4 lbs.

(2) To produce 100 lbs. of tool steel.

Best Swedish bar iron (cut)	75 lbs.
Tungsten powder (96 to 98% W)	18·5 lbs.
Ferro-vanadium (35 to 40 % V)	1.0 lbs.
Ferro-chrome (60% Cr)	8·0 lbs.

(3) To produce 100 lbs. of tool steel.

Best Swedish bar iron (cut)	55 lbs.
Tungsten powder (96 to 98% W)	26 lbs.
Ferro-chrome (60% Cr)	12 lbs.
Ferro-molybdenum (80% Mo)	9·5 lbs.
Ferro-vanadium (35 to 40 %V)	1·0 lbs.

[1] "Revue de Métallurgie," 1904, p. 334.

In each example, the ferro-additions are added to the charge of liquid iron. From the foregoing analyses and charges it is obvious that the compositions of tool steels admit of wide variations.

Carbon Tool Steels.—In Table XLIX a list is found of various tools made from carbon steels having the analyses given. Different steel makers have their own analyses for the particular classes of steel they manufacture. The following percentage analyses are given as typical only.

TABLE XLIX

ANALYSES OF CARBON TOOL STEELS

Tools.	Carbon.	Silicon.	Manganese.	Phosphorus.	Sulphur.
Small machine tools, drills, cutters, razors.	1·3 to 1·4	0·01	0·20	0·008	0·01
Medium machine tools, drills, cutters, knives, chisels.	1·0 to 1·15	0·015	0·25	0·012	0·014
Heavy machine tools, large circular cutters, reamers, taps, and dies.	0·85 to 0·95	0·015	0·22	0·015	0·015
Cold chisels, hot and cold setts, shear blades, small smiths tools, and punches.	0·7 to 0·8	0·02	0·2	0·015	0·015
Snaps, hammers, dies, stamping dies, and like tools.	0·55 to 0·65	0·02	0·24	0·02	0·02

Carbon Tool Steel Charges.—To produce carbon tool steel, various mixtures are used, and the three charges given are typical only:—

(1) To produce 100 lbs. steel.

Best Swedish bar iron	60 lbs.
Carbon steel scrap	42 lbs.

Small percentages of carbon, ferro-alloys, and aluminium are melted with or added afterwards to the melted charge, to produce the temper required.

(2) To produce 100 lbs. steel.[1]

Best Swedish bar iron		45 lbs.
Carbon steel scrap		25 lbs.
Punchings		20 lbs.
Washed metal		10 lbs.
Charcoal		5 ozs.
Ferro-chrome	3 ozs.	Added to the above when melted.
Ferro-manganese	4 ozs.	
Aluminium	½ oz.	

(3) Materials used for producing 2000 lbs. of liquid steel suitable for a common grade of tool steel[2]:—

Wrought iron	1360 lbs.
Heads, gates, etc.	660 lbs.
Defective castings	10 lbs.
Ferro-alloys	12 lbs.
Total	2042 lbs.

[1] "The Foundry," vol. 37, p. 42.
[2] "The American Foundrymen's Association," vol. 18, p. 217.

Steel Castings Charges.—The compositions of steel made by the crucible process for castings admit of even a wider range than that of tool steels. The mixtures or charges may be entirely of very mild steel boiler plate punchings, or of wrought iron, or they may consist of mild steel scrap and pig iron in different proportions and qualities according to the quality of the castings required. The following are a few sample charges :—

(1) Where boiler plate punchings are used only, 100 lbs. closely packed into the crucible. Analysis of punchings :—

C 0·15% ; Mn 0·26% ; P 0·05% ; S 0·04%.

When the charge is melted, the following additions are made :—

Ferro-manganese (80% Mn)	1 lb.
Ferro-silicion (50% Si)	1 lb.
Aluminium (pure)	$\frac{1}{2}$ oz.

These are broken into pieces about the size of a hazel nut and added to the steel by means of a pipe about 2 inches diameter, through which the materials pass into the crucible while it is still in the furnace. A hole in the furnace cover and also one in the lid of the crucible, admits the pipe to the crucible.[1]

(2) For ordinary steel castings, which after annealing give a tenacity of about 30 tons per square inch, with an elongation of 20 per cent. on 2 inches :—

Mixed steel scrap	60 lbs.
Steel castings scrap	12 lbs.
Hematite pig iron	5 lbs.
Aluminium (added after melting)	$\frac{1}{2}$ oz.

(3) For ordinary steel castings used for general work and subjected to prolonged annealing at high temperature :—

Boiler punchings	35 lbs.
Foundry scrap	9 lbs.
Hematite pig iron	15 lbs.
Ferro-alloys	1 lb.

(4) For ordinary steel castings. Materials to produce 2000 lbs. liquid steel[2] :—

Foreign steel scrap (low phosphorus) .	1330 lbs.
Heads, gates, etc.	660 lbs.
Defective castings	10 lbs.
Ferro-alloys	12 lbs.
Total . . .	2012 lbs.

[1] "The Foundry," vol. 37, p. 42.
[2] "The American Foundrymen's Association," vol. 18, p. 217.

PART II

THE BESSEMER PROCESS

CHAPTER XII

THE ACID PROCESS

Historical.—The story of the early struggles, defeats, and successes in developing the Bessemer process has all the fascination of a romance. Sir Henry Bessemer, in an autograph letter which was presented to the American Institute of Mining Engineers by the then Sir James Kitson, Bart., has given a graphic account of what led to the experiments which ultimately brought him so much well-earned renown. While engaged with projectile trials in the fortress at Vincennes, an officer made a casual remark about superior material for guns, which arrested Bessemer's attention. "This casual observation," says Sir Henry, "was the spark that kindled one of the greatest industrial revolutions that the present century has to record, for, during my solitary ride in a cab that night from Vincennes to Paris, I made up my mind to try what I could to improve the quality of iron used in the manufacture of guns."

It was at the Cheltenham meeting of the British Association on Aug. 11th, 1856, that Sir Henry Bessemer made known to the world his process. Licences were in great demand. The idea of converting iron into steel in a few minutes without the aid of external fuel was startling, and aroused the curiosity of manufacturers of wrought iron. But the imperfect knowledge of the chemical reactions in the process and the influence of the volume and pressure of air, as well as a wrong conception that any class of pig iron could be used in the process, contributed to a rapid reversal of opinion regarding the merits of the discovery.

Other investigators in this country and abroad had been working towards the same object. The interest aroused by the patent of Joseph Gillott Martien, of Newark, New Jersey, U.S.A., dated Sept. 15th, 1855, and the experiment of Mr. George Parry, of the Ebbw Vale Ironworks, in October or November, 1855, have long since been forgotten. Dr. Percy,[1] in referring to Mr. Parry's experiment, says that "if an accident had not unfortunately occurred, Bessemer might have been shorn of his glory."

On Jan. 10th, 1857, William Kelly obtained his first American patent, and claimed, says Mr. R. W. Hunt,[2] "priority in the discovery of the principles of the process, and the Patent Office allowed his claim by granting him patents." Bessemer had, however, obtained patents for his process in America dated Feb. 12th, 1856, and Aug. 25th of the same year, and while the Kelly Pneumatic

[1] Percy's "Metallurgy: Iron and Steel," p. 812.
[2] "Trans. American Institute of Mining Engineers," vol. 5, p. 201.

Process Co., which was formed in 1863 and finally abandoned in 1869, was allowed to operate the patents of Kelly, and was the first to make Bessemer steel in America at the works at Wyandotte, in the fall of 1864, under the direction of Mr. W. F. Durfee, it has long since been admitted that the inner and governing principle of the great discovery emanated from the brain of the genius Henry Bessemer.

The pioneer of the Bessemer process in America, and one to whom all steel men would readily award the honour of having very largely contributed to its development and success, was Mr. Alexander M. Holley. It was he who negotiated with Bessemer the American patent rights for the Winslow, Griswold, and Holley Co., and started, in Feb., 1865, the first $2\frac{1}{2}$-ton converter at Troy, New York, thus inaugurating the Bessemer steel production of America, which, during the year 1911, amounted to 7,947,849 tons.[1] Mr. Robert W. Hunt,[2] in his presidential address in 1906 to the American Institution of Mining Engineers, said, in referring to American Bessemer practice, "that the names of Holley, John Fritz, George Fritz, William R. Jones, Daniel L. Jones, and Robert Forsyth furnish a galaxy of talent which makes plain why America so soon forged to the front in Bessemer steel production."

Going backwards to the introduction of the process in this country, perhaps the most eventful years in the early history of the process were the first two, during which Bessemer had cause to reflect that he had too readily granted licences for a process the full significance of which was not at first realised by himself. While he was struggling to perfect his process, others were experimenting with the same object. James Riley tells[3] of a crude experiment made in 1857 at the Coats Iron Works, Scotland, by Mr. Thomas Jackson, and afterwards of experiments at the works of William Dixon, Ltd., all of which were unsatisfactory. To Robert Mushet, in this country, and to F. Goransson, in Sweden, the commercial success of the process is largely due. Professor Åkermann,[4] referring to Goransson's early experiments with the Bessemer process at the Edske blast furnace works in 1857, says that, "until the middle of 1858, he, like Sir Henry himself, had succeeded only exceptionally in turning out a good product while following the advice of the inventor to lay the greatest weight on having a high pressure of blast. By departing from that advice, by means of larger tuyere area and an abundant supply of blast, Goransson was able, beginning with July 18th, 1858, so to shorten the time necessary for the process, and thereby increase the heat of the blow, that an improved product was obtained; and from that day forth the success of the Bessemer process was first assured." Professor Åkermann also tells how Goransson sent 15 tons of ingots to Sheffield, made by his improved method, while Bessemer was still struggling to make good steel. It would appear that the improvement made by Goransson impressed Bessemer, who, for two years after the Edske trials, used Swedish pig iron only in his converter at Sheffield.

It was recognised in this country that Robert Mushet's patent of Sept. 22nd, 1856, had a considerable influence in removing from Bessemer steel the red shortness which, among other difficulties, Bessemer was then endeavouring to overcome. The injurious presence of sulphur in ores, the relation of which to the other elements in the iron was not so fully understood then as now, was counteracted by additions of manganese, and to this day the value of manganese in Bessemer pig irons is well known. It is, of course, understood that the Bessemer process admits of the use of numerous varieties of pig irons, many of

[1] "Mineral Industry," 1911, p. 429.
[2] "Trans. American Institute of Mining Engineers," vol. 37, p. lix.
[3] "Journal Iron and Steel Institute," 1885, II, p. 394.
[4] "Trans. American Institute of Mining Engineers," vol. 22, p. 266.

which are low in manganese; but the balance of the heat-giving elements—silicon, manganese, and carbon—must be maintained to produce good steel, in which the presence of manganese is necessary for success.

Apart from certain improvements in the mechanical features of the process, nothing particularly striking took place until the introduction of the basic lining in the converter by Thomas & Gilchrist, to which reference is made in Chapter XIII.

The "Acid Bessemer Process," besides other large steel processes, has benefited by the use of the mixer, introduced first by Captain Jones at the Edgar Thompson Works, U.S.A., in 1890, and simultaneously in Germany. Much of the irregular quality of steel produced was due to the variation in the metal taken direct from the blast furnace. The use of the intermediate process of remelting in the cupola is still common in many works, although where the mixer is installed there is not now the same necessity for it as formerly. The practice of using iron direct from the blast furnace was first introduced by Goransson, in 1857.

The Bessemer Process.—The outstanding features of the Bessemer process are better appreciated by contrasting this process with other processes. All steel manufacture is based upon the elimination, by means of oxidation, of certain metalloids from the iron used in the manufacture. The processes differ one from the other principally in the methods employed in carrying this into effect. In the crucible steel process, oxidation takes place in a very small degree and at a slow rate, because very little air is allowed to enter the crucible to promote oxidation. Also the action of the materials of which the crucibles are made and the oxides of iron in the materials melted are too feeble to form slags in any marked degree. A more accelerated rate of oxidation takes place in the molten bath of metal in the open-hearth furnace where various mineral oxides, as well as the oxygen in the atmosphere which unites with the hot gases passing into the furnace, contribute to the rapid oxidation of the impurities in the raw materials during the process of conversion to steel.

In the Bessemer process a very much more rapid oxidation of the metalloids in the molten metal takes place, not because heat is applied from external sources as is necessary in the other processes of steel manufacture, but because of the enormous and extremely rapid generation of internal heat due to the chemical actions and reactions produced by the oxidation of the principal heat-giving elements in the molten pig iron under the influence of a volume of air passing through the metal at high pressure, without the assistance of any external heat whatsoever. It was very soon discovered that the principal heat-giving elements were silicon, manganese, and carbon, but the presence of other elements, such as phosphorus and sulphur, was not only objectionable, but could not be oxidised by the oxygen in the same way as silicon, manganese, and carbon. As the separation of phosphorus and sulphur was a hopeless task by the acid process, the process was limited to the conversion of pig irons which were free from harmful proportions of these elements. The commercial scope of the acid process demanded the use of iron containing not more than 0·06 per cent. P as a maximum, and 0·06 per cent. S; and steel with these proportions was only applicable to certain classes of work where the ductility was not a matter of importance. Until the introduction of the basic lining in the Bessemer converter, many ore deposits were quite unsuitable for the Bessemer process.

The oxidation of silicon in the first stage of the process provides more heat than any of the other elements, and consequently raises the temperature of the bath and makes possible the rapid conversion of the carbon at a later stage to CO_2 and CO. The manganese in the iron is also oxidised in the first stage as

well as a portion of the iron and a very small amount of carbon. The order may be briefly stated as follows:—

1. The conversion of a large percentage of silicon to silicate of iron, together with the oxidation of manganese, both of which form slags.
2. The carbon which has been slightly oxidised soon after the commencement of the blow, now passes off as CO_2 and CO at a gradually increasing rate, violent ebullitions taking place meanwhile during that part of the process known as the "boil."
3. The final period is confined almost entirely to the elimination of the carbon, the heat being most intense and the carbon being burnt chiefly to CO.

These 3 periods are also very well defined by the colour and form of the flame which issues from the mouth of the converter:—

1. The issue of brown fumes accompanied with sparks, the lighting of the gases into a short flame and burning to a bright yellow and longer flame are the significant features.
2. The "boil," during which so much internal disturbance takes place, sometimes heaving large masses of slag from the vessel, is accompanied by a more intense and more luminous flame of varying length.
3. The "carbon stage," which is of long or short duration according to the amount of carbon left after the "boil" is over, is quite distinct from the two earlier stages. It is characterised by a clear long white flame tinged with blue, curling in woolly form at the mouth of the converter, and having long, fork-shaped tongues of fire several feet long. When the carbon is nearly exhausted, a pronounced "drop" in the flame takes place and the flame becomes discoloured with fumes of iron oxide, the definite sign to turn down the vessel.

The Progress and Duration of the Process.—The rate of oxidation of the impurities in the metal during the process is dependent upon at least three things:—1st, the analysis of the pig iron employed; 2nd, the temperature of the metal at the commencement of the blow; and 3rd, the rate of production, or the interval between each blow. In this country it is common to use pig iron which contains from 2 to 3 per cent. of silicon, with manganese from 0·5 to 1·25 per cent. while in America it is more general to use pig irons with about 1·0 to 1·75 per cent. silicon with 0·7 to 1·0 per cent. manganese. In Sweden, the pig iron generally used does not contain more than 1·0 per cent. silicon with 2·0 to 4·0 per cent. of manganese.

Where pig iron is practically free from phosphorus and sulphur, any of the above classes of iron will give satisfactory results, but the blow will be prolonged according to the excess of silicon and manganese over that required to produce the heat necessary for the conversion of the metal. The following examples illustrate how high and low silicon pig iron charges influence the rate of output.

Pig Iron Charge with Low Silicon and Low Manganese.—In the case of very low silicon pig irons such as are used in some works in America, with low manganese content as well, it is only possible to obtain successful heats when one blow follows another in rapid succession. Howe,[1] in his notes on the Bessemer process, refers to a typical American blow in which the composition of the metal and slags at various stages of the process are given. From Table L it will be observed that in 9 mins. 10 secs., 10 tons of iron are converted to steel, that is at the rate of over 1 ton per minute.

[1] "Journal Iron and Steel Institute," 1890, II, p. 95.

TABLE L

PERCENTAGE ANALYSES OF METAL AND SLAG DURING BLOW

	Initial charge.			Time of actual blowing.						Analysis of Spiegel added.
	Molten metal.	Steel scrap (estimated).	Average.	2 min. 0 sec.	3 min. 20 sec.	6 min. 3 sec.	8 min. 8 sec.	9 min. 10 sec.	After adding Spiegel. 9 min. 20 sec.	
Carbon	3·10	0·36	2·98	2·94	2·71	1·72	0·53	0·04	0·45	4·64
Silicon	0·98	0·08	0·94	0·63	0·33	0·03	0·03	0·02	0·038	0·35
Manganese	0·40	0·97	0·43	0·09	0·04	0·03	0·01	0·01	1·15	14·90
Phosphorus	0·101	0·10	—	0·104	0·106	0·106	0·107	0·108	0·109	0·139
Sulphur	0·06	0·08	0·06	0·06	0·06	0·06	0·06	0·06	0·059	—
Slag—										
SiO_2	—	—	—	42·4	50·26	62·54	63·56	—	62·20	—
Al_2O_3	—	—	—	5·63	5·13	4·06	3·01	—	2·76	—
Ferrous oxide	—	—	—	40·29	34·24	21·26	21·39	—	17·44	—
Ferric oxide	—	—	—	4·31	0·96	1·93	2·63	—	2·90	—
MnO	—	—	—	6·54	7·90	8·79	8·88	—	13·72	—
CaO	—	—	—	1·22	0·91	0·88	0·90	—	0·87	—
MgO	—	—	—	0·36	0·34	0·34	0·36	—	0·29	—
P	—	—	—	0·008	0·008	0·010	0·014	—	0·10	—
S	—	—	—	0·009	0·009	0·014	0·008	—	0·11	—
Appearance of Flame	—	—	—	Si flame	Brightening	Mod. C flame	Full C flame	Flame drops.	Blown 10 secs. after drop	—
Cubic feet of air used	—	—	—	34,502	30,628	53,481	45,365	26,430	1,868	
Cubic feet of air per minute	—	—	—	17,251	22,971	19,691	21,810	25,685	11,208	

The heat absorbed and evolved by the chemical reactions during the removal of the carbon, silicon, and manganese can be calculated approximately only. Some difference of opinion exists as to the number and arrangement of various carbide combinations which are known to exist in the metal at high temperatures, the decomposition of which means the absorption of heat. The losses due to radiation and escape of heat through gases and slags which issue from the converter are very considerable, but the balance of heat after deducting all losses is such as to raise the temperature of the bath several hundred degrees Centigrade during the conversion of one charge of metal. In Fig. 46 are shown curves prepared from the details given in Table L, which graphically illustrate the rate of elimination of carbon, silicon, and manganese.

To maintain the output of steel when using pig iron containing so little silicon and manganese, it is necessary to have the iron from the blast furnace, cupola, or mixer very hot and ready to pour into the converter as soon as the previous charge is emptied into the ladle. If this is not done the temperature of the converter lining chills very rapidly.

Pig Iron Charge with High Silicon and Low Manganese.—In Table LI are given the analyses of the metal at different stages during the blow in an 8-ton Bessemer converter upon which investigations were made by Mr. C. F. King[1] at the Bethlehem Iron Co.'s Works. The analyses of the metal used and the steel produced were as follows :—

[1] "Trans. American Inst. of Mining Engineers," vol. 9, p. 259.

Metal used.—C 3·56 per cent.; Si 2·398 per cent.; Mn 0·491 per cent.
Steel produced.—C 0·034 per cent.; Si 0·043 per cent.; Mn 0·105 per cent.
∴ the removal of C, Si, and Mn in 18 minutes amounted to—

C 3·526 per cent.; Si 2·355 per cent.; Mn 0·391 per cent.

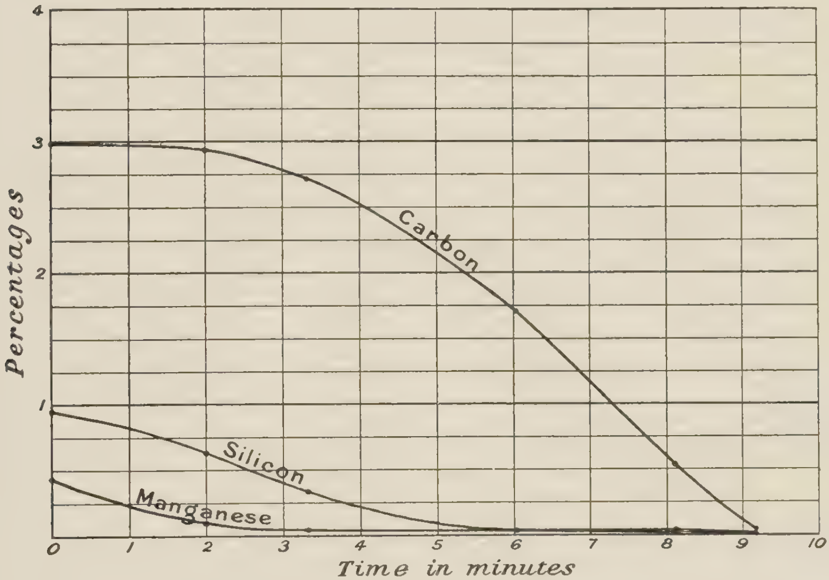


FIG. 46.—Rate of Oxidation of Carbon, Silicon, and Manganese during Blow given in Table L.

TABLE LI

PERCENTAGE ANALYSES OF METAL DURING BLOW

	1. Metal charged	2. 8 mins. after start.	3. 15 mins. after start.	4. 17 mins. after start.	5. 18 mins. after start.	6. Analysis of Spiegel added.	7. Final product.	8. Analysis of scrap used.	9. Spiegel reduced to 10·6 % of charge.
Specific gravity	6·866 6·818	7·487	6·447 6·200	7·369 7·114	6·706 6·792	7·49	6·691 6·459	7·541	— —
Total carbon %	3·543 3·560	3·199 3·231	1·230 1·270	0·207 0·207	0·034 0·034	4·338 4·396	0·367 0·374	0·264 0·264	0·460 0·460
Graphite %	3·16 3·17	0·415 0·438	0·236 0·272	0·0297 0·0273	0·0095 0·0094	0·824 0·827	0·0187 0·0188	0·0149 0·0146	0·087 0·087
Combined carbon %	0·383 0·390	2·784 2·783	0·995 0·999	0·1775 0·1797	0·025 0·025	3·569 3·514	0·349 0·356	0·2491 0·2497	0·378 0·372
Silicon %	2·384 2·398	1·07 1·10	0·108 0·107	0·058 0·056	0·037 0·043	0·67 0·68	0·060 0·061	0·103 0·117	0·071 0·072
Manganese %	0·496 0·491	0·151 0·150	0·133 0·134	0·129 0·130	0·097 0·105	16·129 16·1569	1·175 1·166	1·229 1·212	1·710 1·713
Phosphorus %	0·089	—	0·092	0·076	—	—	0·0897	—	—

When compared with the low silicon charge in Table L, which was completed in 9 min. 10 secs., it will be noticed that the silicon content was 2·398 per cent. as against 0·94 per cent. in the charge which took 9 mins. 10 secs. to complete. The rate of oxidation of the charge given in Table LI is shown in Fig. 47. The temperature of the metal at the commencement of the charge is not given for either of the charges described, but this has an important bearing on the rate at which the impurities are removed. If the temperature is rather lower than usual, it may be a few minutes before any appreciable amount of silicon is removed, and little if any carbon, the iron meanwhile being oxidised. On the other hand, when the temperature is high, the silicon rapidly oxidises. It has been found

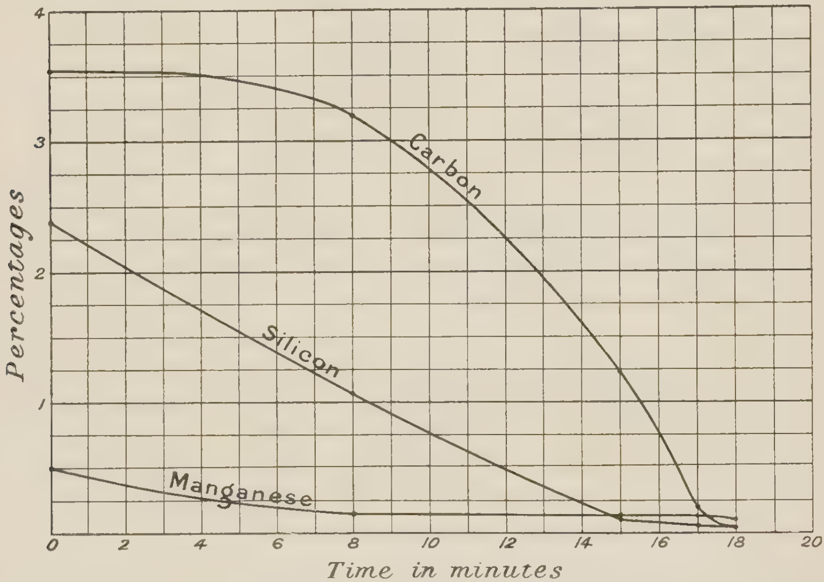


FIG. 47.—Rate of Oxidation of Carbon, Silicon, and Manganese during Blow given in Table LI.

that when the temperature of the metal is very high, the carbon is attacked before the silicon, leaving a silicious steel as the result of the blow.

Some experiments in which we were interested revealed this very fact. It was found necessary under certain circumstances to melt the Bessemer pig iron in an open-hearth furnace, instead of in the usual cupola, the result being that a reduction in the carbon and silicon content took place. The iron being diluted by means of low carbon steel scrap, yielded a metal for the converter varying in carbon from 2 to 2·5 per cent.; silicon 1·0 to 1·5 per cent.; and manganese from 0·5 to 0·75 per cent. If the temperature were not too high, very rapid blows could be obtained; with an excessive temperature erratic blows would result, in which the carbon was burnt out before the silicon, producing in some cases unsatisfactory steel. These trials were conducted in a 2-ton side-blown Bessemer plant.

In the ordinary bottom-blown converter, the temperature of the metal in the bath is regulated by additions of scrap steel or steam. Scrapping is the common practice in this country and on the Continent. In America the use of steam is also practised. This is carried out by introducing a small pipe, about 2 inches

diameter, into the blast pipe leading to each separate converter, through which steam at about 50 lbs. per square inch pressure is passed.

Swedish Practice.—It is most common in Sweden to employ pig iron for conversion to steel which contains from 0·9 to 1·0 per cent. Si, with not less than 1·5 per cent. Mn, and preferably higher percentages—from 2·0 to 4·0 per cent. Mn. If the manganese is low, and the metal is not very hot, there is the danger of a cold blow. With good hot metal excellent results are obtained, the progress of the blow being the same as in other countries.

British and Continental Practice.—Higher silicon pig iron is more frequently used in this country and on the Continent for the Bessemer process than in America or Sweden. The silicon content varies from 2·0 to 2·5 per cent. or even more, and the blow is longer—sometimes from 20 to 30 minutes. The same outstanding characteristics are observed in the ordinary blow as revealed in Table LI, which in many respects represents British practice. The manganese is perhaps rather lower than the average used in this country.

Additions to the Charge.—The practice in this country and in most countries is to add ferro-manganese to the charge in the proportion required to make the desired steel.

In Sweden it was the practice for many years to stop the blow when it reached that stage of oxidation which left in the steel the amounts of carbon and silicon required. The use of the spectroscope to examine the flame and control the operation accordingly was also common. This practice has not found favour in Britain. The human element enters so much into the question that irregularity of product is likely to result in trying to stop the blow before the carbon has been burned out. The "drop" of the flame is an almost infallible guide to a regular carbon content, and whatever additional carbon is required can be added with more certainty of obtaining correct results than by trusting to the colour and form of the flame.

CHAPTER XIII

THE BASIC BESSEMER PROCESS

Historical.—The Basic Bessemer process differs from the Acid Bessemer process, not in any of the mechanical features of the plant, or in the principle underlying the conversion of iron into steel by the oxidation of the metalloids in the iron due to heat generated from within, but in the metallurgical and chemical differences in the actions and reactions which take place in the oxidation of the chief element, phosphorus. The early struggles to find a suitable refractory lining for the converter and fluxing agent for the phosphorus in the iron, formed one of the chief obstacles in the way of progress. The fact that on the Continent of Europe some of the largest deposits of ore could not be used for the manufacture of iron in the acid-lined vessel, made metallurgists all the more eager to find a means of utilising such valuble iron ore resources.

Many investigators were engaged in the same pursuit, but the discovery of Mr. Sidney G. Thomas and his experiments with those of Mr. Percy G. Gilchrist during the three years prior to placing before the Iron and Steel Institute, in 1879, the result of their researches earned for them the honour of having found a suitable basic lining, which could be employed with commercial success in Bessemer converters for the conversion of high phosphorous pig irons.

No sooner had they demonstrated the value of the process than steel makers from different parts of Germany went to Middlesbrough to witness the results for themselves, and secure the right to use the patented process. Mr. J. Massenez,[1] writing on the history of the Basic process in Germany, states that on April 4th, 1879, Messrs. E. Meier and R. Pink witnessed a demonstration of the process at Middlesbrough with the object of securing the patent rights for Germany, but found that they had been forestalled by Mr. G. Pastor. By arrangement, the patent rights were ultimately secured for Germany and Luxemburg by the representatives of both the Rheinische and the Hörde works, the patent rights for Austria and Hungary being secured by the latter company. It was on Sept. 22nd, 1879, when the first charges were blown simultaneously at the works of both Rhenische and Hörde, the capacity of the converter used at the former being 3 tons. The first basic steel rails produced in Germany were made on the same day, and found quite satisfactory. Since then the industrial prosperity of Germany has been very largely connected with the development of the Basic process.

Basic Linings.—The greatest difficulty experienced by the users of the new process was in finding suitable materials for producing durable linings. In the experiments carried out by Thomas and Gilchrist in the 4-cwt. converter vessel at Blaenavon,[2] where some 50 or more blows were made, the principal linings

[1] "Stahl und Eisen," vol. 29, pp. 1465–1477.
[2] "Journal Iron and Steel Institute," 1879, I, p. 123.

were composed of (*a*) limestone and 10 per cent. silicate of soda, and (*b*) limestone and 10 per cent. fireclay, but in making basic bricks afterwards for practical use in steel works, the experiments which have been made with different compositions and methods of manufacture are too numerous even to name. Bricks, however, made mainly of lime, with a little magnesia and about $2\frac{1}{2}$ to 3 per cent. of silica, were used with much success in Austria and Germany, and by some English makers for the linings and bottoms of converters.[1] Sometimes linings have been made of bricks of caustic lime obtained from pure limestones, but it has been more general to use the combination of lime and magnesia in the form of calcined dolomite. Magnesite bricks, as well as chrome iron ore, have also found their place in the development of basic linings for converters. The processes of manufacture of materials for the various kinds of linings, including calcining, grinding, mixing, and drying, have demanded the attention and skill of many experimentalists.

Basic Fluxes.—While the history of the basic lining is full of interest, the researches made in endeavouring to obtain suitable fluxes to provide a ready means of eliminating the impurities in the metal with a minimum of loss both to metal and lining, warrant no less consideration. Both Thomas and Gilchrist[2] discovered in their early experiments that "the presence of a considerable amount of lime in a not too silicious slag is highly favourable, and on a large scale essential, to the removal of phosphorus." They recognised, also, that lime and the oxide of lime are fusible in many proportions and could be used with advantage in the proportions by weight of one-third "Blue Billy"[3] to two-thirds lime. In both these facts they laid the foundation for research, which has brought forth ample varieties of the application of lime and iron oxides in different proportions introduced to the metal at different periods during the conversion of phosphoric pig iron to steel.

One other important fact, observed by both Thomas and Gilchrist, which has remained vital to the process, is what is known as the "after blow." In the Acid Bessemer process, when the carbon is burnt out, the metal is immediately attacked and the steel destroyed if the blow is prolonged. Contrary to this experience, they found that the greater part of the phosphorus was not removed until after the carbon was oxidised, hence the continuation of the blowing for a few minutes, which is termed the "after blow."

Development of the Basic Process.—Associated with the development of the Basic Bessemer process are the names of many well-known metallurgists and steel experts in this and other countries, such as Snelus, E. W. Richards, Martin, Percy, Stead, Wedding, and other investigators, who have more recently carried out research.

When continental steel-makers acquired the rights to use the basic process, suitable native ones favoured its development in their hands. The difficulties referred to regarding lining and fluxes were small compared with the advantages gained by the employment of native instead of foreign iron. Steel works in Germany, Austria, and France were speedily making use of the new process, while in England, the country in which it was discovered, only tardy progress was made. The reason for this is found in the fact that the phosphoric ores in Great Britain, particularly the Cleveland ores, did not encourage the production of basic pig iron. The presence of a high percentage of silicon, with a comparatively low phosphorus content, gave rise to rapid wastage of converter linings, and larger quantities of lime had to be added in order to obtain a

[1] "Journal Iron and Steel Institute," 1881, II, p. 403.
[2] *Ibid.*, 1879, I, p. 123.
[3] "Blue Billy" contains on an average 96 per cent. of Fe_2O_3 (Phillips, "Elements of Metallurgy," p. 309).

sufficiently basic slag. A very considerable waste of iron, however, was the result.

The rapid wastage of linings was largely reduced when manganiferous ores were mixed with English ores, which produced a basic iron high in manganese and low in silicon. This, however, led to an increased cost in making the pig iron, and consequently put Britain in a less favourable position to compete with her foreign rivals.

Several modifications in the Basic Bessemer process have been made in order to improve the manufacture of steel. They have consisted chiefly in modifications of the amount of lime and oxides of iron used for producing a highly basic slag, the object being to reduce the cost of production and more easily to adopt the process to the various kinds of basic iron manfactured. These improvements have been effected not in this country alone, but wherever the process has been in operation.

The Pig Iron Mixer.—Another stage in the development of the process which contributed greatly to the production of more uniform results, took place with the introduction of the pig iron mixer. In the very earliest use of the basic converter it was found that in taking the metal direct from the blast furnace to the converter, skulls were often left in the ladles owing to the chilling of the metal during transit. Then, again, cold charges were most troublesome, as the heating value of the phosphorus in the iron was not felt at the commencement of the blow, and in consequence of the necessity for having a low percentage of silicon in the metal and a large amount of lime in the vessel, the odds were against a good start if the metal was not very hot when charged.

As the result of irregular heats from the blast furnaces, cupolas for remelting the pig iron were mostly always used, although open-hearth furnaces were employed at some of the works in Bohemia for the same purpose, chiefly because coke was so expensive. The cupola is still used in some of the largest steel works, and at Kladno[1] 6 Siemens furnaces are used for remelting pig iron for four 13-ton Basic Bessemer converters, but the mixer has been a most acceptable adjunct not only to the Basic Bessemer process, but to every type of furnace used in the various processes where liquid metal is employed.

The mixer is simply a magnified cupola receiver, mounted, of course, differently from the ordinary external cupola attachment, and is being used now in some works as a refining furnace as well as a store for metal. Its simultaneous introduction into Germany and America about the year 1890 has done, perhaps, more for the Basic Bessemer process than for any other, because of the necessity of having metal of a fairly uniform analysis and at a high temperature.

The Blow.—When the basic lined converter is well heated (it is absolutely necessary that the converter be thoroughly hot), hot burnt lime, sometimes mixed with coal and coke, is put into the converter. The blast is turned on gently and maintained for a few minutes in order to get a good white heat glow from the interior, after which the basic iron is charged. When the blow is started, the first three elements in the iron to be oxidised are silicon, manganese, and carbon respectively, after which the phosphorus is reduced rapidly.

It has been shown by Wüst and Laval[2] that about 25 per cent. of the phosphorus in the metal is removed during the oxidation of silicon, manganese, and carbon, and the remainder during the "after blow." From Table LII, which gives the analysis of the charge at different stages of the blow, it will be observed that this actually takes place.

[1] "Journal Iron and Steel Institute," 1907, III, p. 263.
[2] "Stahl und Eisen," Jan. 2nd, 1909, pp. 121–133.

TABLE LII

PERCENTAGE ANALYSES OF CHARGE DURING BLOW

Blowing time, Minutes.		C	Si	Mn	P	S
	Pig iron	3·354	0·481	0·85	2·009	0·177
0 to $1\frac{1}{2}$	1	3·081	0·036	0·80	1·998	0·098
$1\frac{1}{2}$,, $3\frac{1}{4}$	2	2·624	0·006	0·42	1·910	0·120
$3\frac{1}{4}$,, $5\frac{1}{4}$	3	1·934	0·007	0·41	1·886	0·128
$5\frac{1}{4}$,, $6\frac{3}{4}$	4	1·321	0·009	0·45	1·786	0·128
$6\frac{3}{4}$,, $8\frac{1}{4}$	5	0·733	0·010	0·55	1·735	0·128
$8\frac{1}{4}$,, 10	6	0·094	0·005	0·52	1·436	0·112
10 ,, $11\frac{3}{4}$	7	0·034	0·009	0·55	0·526	0·067
$11\frac{3}{4}$,, $13\frac{1}{4}$	8	0·015	0·009	0·34	0·117	0·084
$13\frac{1}{4}$,, 15	9	0·016	0·013	0·23	0·066	0·077
	Steel	0·26	0·033	0·88	0·097	0·059

The table above also serves to show with what rapidity the reactions take place. This is, of course, dependent upon the composition of the iron, the temperature of the bath, and the character of the slag present. It will be noticed that the silicon is reduced to a trace in 2 to 3 minutes, the carbon being almost entirely removed during the first period, which occupies from 8 to 10 minutes. The dephosphorisation then proceeds rapidly, when carbon is practically absent. If the temperature of the iron at the commencement of the blow is high, then carbon burns more rapidly, and the time of the blow is shortened. The affinity of carbon for oxygen increases more as the temperature rises than does the affinity of iron and manganese for oxygen. The best results in the basic process are obtained when the temperature of the metal is high at the commencement, and not too hot during the "after blow." The practice in some works of charging scrap into the converter with the molten pig iron does not encourage a good start, unless the molten pig iron from the mixer is very hot. During the "after blow" the conditions are reversed, and a lower temperature promotes more rapid oxidation of phosphorus, seeing that the affinity of the latter for oxygen grows less as the temperature of the already very hot metal rises. While under such condition the iron is attacked and oxidised, and also any manganese left in the metal.

Therefore, with a cold heat to start, slow oxidation of the carbon proceeds with a more rapid oxidation of manganese and loss of iron; with a hot "after blow" in the same heat, the slow oxidation of the phosphorus proceeds without sufficient manganese being left to protect the iron from oxidation, hence considerable waste is produced.

To cool the blow and maintain a sufficient temperature, various means have been employed. Lime and scrap steel additions have been perhaps most common, but with these universally good results have not been obtained. Lime is a slow conductor of heat, and large additions of scrap tend to produce sluggish metal.

MODIFICATIONS OF THE BASIC PROCESS

Scheibler's Modification.—Professor C. Scheibler[1] obtained good results at several steel works in Germany by the use of lime additions in two stages of the blow, *i.e.* two-thirds at the start, before charging the metal, and one-third during the "after blow." The total amount of lime used was roughly one third less

[1] "Proceedings Institution of Civil Engineers," vol. cxx, p. 437.

than that used in ordinary practice. Different results were obtained in the various works where his modification was introduced. At Gutehoffnungshütte, for instance, the first charges finished so hot that a large addition of scrap was necessary to cool the steel, while at the Rhenish Steel Works the second addition of lime was found to have a strongly chilling effect, and considered suitable only with pig iron which produced "hot blowing." For basic iron with lower silicon and phosphorus, the use of the whole quantity of lime at the commencement of the blow was preferred, as otherwise the finished charge could only be cast with difficulty.

Flohr's Modification.—Another modification, introduced by J. Flohr, has been specially applicable to the better regulation of the heat in the "after blow." Lime to the extent of about 13 per cent. of the weight of the charge is added before the metal, and just as the second period of the blow is approaching, when the carbon has been almost entirely removed, briquettes consisting of rolled scale, well screened, ground, and mixed with slaked lime, are thrown into the converter. The effect produced upon the metal causes a rapid reduction of the phosphorus, thus shortening the "after blow" and reducing the waste of iron throughout the heat. The phosphoric acid in the slag is also increased, due to the presence of dissolved ferrous oxide, which increases the capacity of the slag for absorbing phosphoric acid.

The composition[1] of the briquettes is as follows:—

Iron shot	1·06 %
Iron oxide	31·40 %
Ferrous oxide	44·70 %
Lime	9·89 %
H_2O	4·16 %
CO_2	0·68 %

Richards' Modification.—Another modification of the basic process, which has proved very economical when using English high-silicon phosphoric pig iron, is that which was introduced by Mr. A. W. Richards at the works of Messrs. Bolckow, Vaughan & Co., Ltd., and has since been in operation in another steel works in this country with marked success.

"In working the process," says Mr. Richards,[2] "some iron oxide is put into the basic converter, preferably an iron ore not too refractory, with or without a small quantity of lime, and on this is poured molten grey Cleveland iron, always low in sulphur, with silicon which may vary from 1·5 to 3 per cent." The operation differs from the ordinary basic process in one respect only, that is in stopping the progress of the blow after the silicon is oxidised and the carbon flame appears, and turning down the vessel for the removal of the slag, which can be poured off the bath of metal. By this means the excess of silicon in the pig iron, which was formerly most troublesome, is removed in the first slag without any serious loss of iron. The analysis of the first slag shows that it contains 3 per cent. of iron, 35 to 45 per cent. of silica, and no phosphorus.

The greatest gain by this modification of the process is the use of the Cleveland grey pig iron, made from the native ores, without the introduction of imported manganese ores which were formerly considered necessary.

The ordinary basic iron used in this country contains—

Si	0·5 to 1·0 %
Mn	1·5 to 2·0 %
P	1·8 to 3·0 %
S	0·06 to 0·08 %

[1] "Engineering," vol. 85, p. 65.

[2] "Journal Iron and Steel Institute," 1907, I, p. 105.

The Cleveland grey pig iron contains :—

Si	1·5 to 3·0 %
Mn	0·5 to 0·75 %
P	1·45 to 1·55 %
S	0·04 to 0·06 %

Mr. Richards found the average loss from fluid iron to steel ingots during 18 months' work with the new process to be 12½ per cent. He also found that although the delay caused by stopping the blow and slagging amounted to 4 minutes during each heat, the time of the whole operation was less, due to the shortening of the "after blow" and more rapid action throughout the heat. The yield of steel amounted to 87½ per cent. of the metal charged, as against 84 per cent. by the other process.

The name of Richards has been associated with the basic process since its inception. It was at the works of Messrs. Bolckow, Vaughan & Co., Ltd., where the practical value of the Basic Bessemer process was tested and realised.

Miscellaneous Modifications.—In the basic process, as in the acid process, many attempts have been made to reduce the cost and produce better steel by heating the blast, drying the air, and blowing solid materials in with the blast with the object of heating and oxidising the bath, but most of them have proved unsatisfactory.

In heating the blast it was contemplated that the blow would be shortened as in the acid process, but actual experience proved that better results were obtained by cooling the air.[1]

Dry air was found satisfactory, but the apparatus required for drying was considered a barrier to its general introduction.

Among the heat-producing agents used with the blast for accelerating the heat in the early stage of the blow, anthracite dust, coke dust, charcoal, coal tar oil, carbonic oxide, etc., may be mentioned.

Wedding[2] says that materials such as powdered limestone, dolomite, magnesia, raw or burnt fluorspar, carbonate of soda, and all possible alkali salts and compounds of manganese, have been used to replace the basic additions and to liquefy the slag, but have proved failures.

One element to which reference has not been made here, though nevertheless important, is sulphur. Its presence in the charge is most objectionable and difficult to remove. High percentages of manganese favour its removal. Practice shows[3] that as much as 50 per cent. of the sulphur in the metal can be eliminated in the basic process by the presence of manganese.

Heat Evolved and Absorbed during the Process.—The Bessemer process is essentially dependent upon the heat supplied with the liquid iron and the oxidation of the metalloids contained therein. Many writers have gone fully into the thermo-chemistry of the process, but we would refer students to Harbord's excellent work on this subject.[4] The measurement of the heat evolved in the gases during the process can be taken approximately by means of optical pyrometers.

Wüst and Laval, who have made several valuable investigations on the heat of the Bessemer process, used a Wanner optical pyrometer (carefully checked by a Le Chatelier pyrometer) for recording the flame temperatures given in Table LIII.

[1] Wedding, "Basic Process," p. 111.
[2] *Ibid.*, p. 115.
[3] *Ibid.*, p. 215.
[4] Harbord, "Metallurgy of Steel," pp. 101–109.

The following table gives the average results of the temperature readings of seven heats :—

TABLE LIII

AVERAGE TEMPERATURE OF THE FLAME IN DEGREES C.

Blowing time in minutes	$1\frac{1}{2}$	2	$3\frac{1}{4}$	$5\frac{1}{4}$	$5\frac{1}{2}$	$6\frac{3}{4}$	$8\frac{1}{4}$	$8\frac{1}{2}$	
Temperature in degrees C.	1041	1093	1155	1251	1263	1260	1287	1291	
Blowing time in minutes	10	$11\frac{3}{4}$	$12\frac{1}{2}$	$13\frac{1}{4}$	$13\frac{3}{4}$	$14\frac{1}{2}$	15	16	$16\frac{1}{2}$
Temperature in degrees C.	1319	1369	1389	1412	1438	1475	1499	1467	1437

From these results, Wüst and Laval[1] showed the heat relations during the various parts of the process. In a charge consisting of the following materials :—

Pig iron	23,093 lbs.
Lime	293 lbs.
Ferro-manganese (76·7 % Mn)	154 lbs.
Ferro-silicon (48·33 % Si)	44 lbs.
Spiegel (9·5 % Mn)	1543 lbs.

they found that the pig iron which contained—

C	Si	Mn	P	S
3·354	0·481	0·85	2·009	0·177

brought 43 per cent. of the total heat into the converter, the remainder, 57 per cent., was supplied by the oxidation of the various elements in the metal.

The heat was used as follows :—

Heat carried away in gases and used to decompose moisture	24 %
Heat used in heating lime and carried away in slags	20 %
Heat lost in radiation	8 %
Heat remaining in steel	48 %

Another method of showing the heat available due to the oxidation of each element, and also the net heat available for raising the temperature during the process has been calculated by Prof. J. W. Richards,[2] and is given in Table LIV.

The degrees given in the end column show the rise in temperature of the bath for every 1 per cent. of element oxidised. The calculations are based on the following temperatures :—

Initial temperature of bath	1250° C.
Final ,, ,,	1600° C.
Temperature of air	100° C.
Temperature of lime added	600° C.

Prof. Richards adds that the above table is for comparison only; it cannot be used for an actual case such as when 1 per cent. of silicon, 3 per cent. of iron, 4 per cent. carbon, and 2 per cent. of phosphorus are oxidised, but that in each specific case calculation be made for the specific conditions obtaining, such as temperature of metal at starting, temperature of blast, time of blow (as far as this affects radiation and conduction losses), proportion of carbon burnt to CO_2, free oxygen in gases, moisture in blast, temperature and quantity of lime added, and corrosion of lining.

[1] "Stahl und Eisen," Jan. 1909, pp. 121-133.
[2] "Electrochemical and Metallurgical Industry," vol. v, p. 14.

Many other investigators, too numerous to mention, have added to the accumulated facts relating to the thermo-chemical actions in the Bessemer process, all of which have been of more or less service to manufacturers.

TABLE LIV

HEAT EFFECT OF OXIDISING 1 KG. OF ELEMENT

	Heat of oxidation. Calories per kilogram.	Heat of formation of slag. Calories per kilogram.	Total heat developed. Calories per kilogram.	Chilling effect of blast, radiation, etc. Calories per kilogram.	Net heat available for raising temperature. Calories per kilogram.	Theoretical rise of temperature. °C.
Silicon	7000	—	7000	1688	5312	188
Manganese	1653	98	1751	430	1320	51
Iron to FeO	1173	159	1332	422	910	33
Iron to Fe_2O_3	1746	159	1905	825	108	42
Titanium	5000	—	5000	1022	3978	150
Aluminium	7272	—	7272	1305	5967	224
Nickel	1051	159	1210	378	832	33
Chromium	3000	—	3000	887	2113	81
Carbon to CO_2	8100	—	8100	3936	4164	143
Carbon to CO	2430	—	2430	2572	−142	−5
Phosphorus	5897	2572	8469	2477 / 2253[1]	3739	133

[1] Chilling effect of lime added, if preheated to 600° C.

CHAPTER XIV

THE EVOLUTION OF THE BESSEMER CONVERTER

In tracing the development and application of this process, many names are linked with that of Sir Henry Bessemer. Perhaps, among the earliest is that of Robert Mushet, who proved the value of manganese in the process of conversion. Later are found the names of Sidney Thomas and Percy Gilchrist in connection with the perfecting of basic linings for the use of a cheap phosphoric pig iron in the converter. During more recent years, Clapp, Griffiths, Walrand, Robert, Zenzes, and Tropenas have developed the side and surface-blown converter processes, although the method of blowing air through the side of a vessel into the liquid iron was tried by Sir Henry Bessemer in his first experiments. The principle of blowing air on the surface of a bath of metal instead of through it was first applied to small converters by Tropenas in 1890. Hitherto it had been considered necessary and indispensable to create a violent stirring action by the passage of air through the bath.

First Experiments.—The stages in the development of the early converters designed and patented by Sir Henry Bessemer are illustrated in the following figures. His first experiments were conducted in a 40-lb. clay crucible in which were melted several pounds of iron, which were afterwards converted into steel by means of a blast of air forced down a clay pipe reaching almost to the bottom of the metal. The crucible was heated in an ordinary furnace, as in Fig. 48. "In this simple apparatus," says Sir Henry Bessemer, "all my first experiments were made."

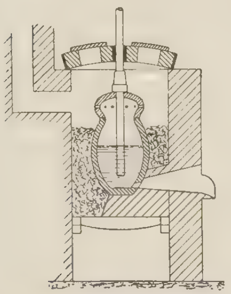


Fig. 48. — Crucible in which Bessemer's first experiments were conducted.

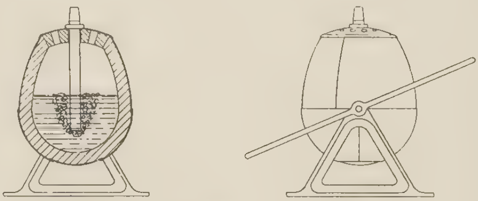


Fig. 49.

Fig. 49 shows sectional and side elevations of a rotating vessel patented in 1855. The clay pipe is shown as passing through the cover into the liquid metal.

In Fig. 50, are given two views of a spherical vessel of the same date, in which he also shows a blast pipe entering at an angle of 45°. This vessel was never actually made.

Converter with Side Tuyeres.—In 1856, before Sir Henry Bessemer commenced making steel in Sheffield, he experimented with a fixed converter at St. Pancras, London. Fig. 51 is a sectional elevation of the converter used, from which it will be observed that this design embodied several features found in the ordinary cupola used for melting iron; the air chamber round the casing, the tuyeres and the taphole, all indicate this. In some respects it might be regarded as a closed cupola. There were six tuyeres round the casing placed near the bottom. Each tuyere was hinged to allow of its being lifted clear of the vessel to admit of cleaning and repairs. The lining was made of Stourbridge firebrick, $4\frac{1}{2}$ inches thick.

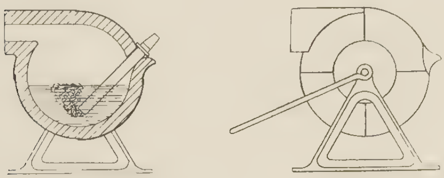


FIG. 50.

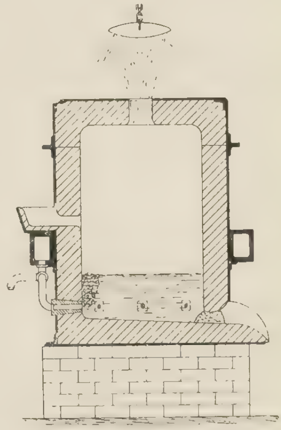


FIG. 51.—Bessemer's converter, in which he carried out his experiments at St. Pancras.

This type of converter was abandoned because he found it was impossible to get the blast to penetrate sufficiently the molten metal, and because of the excessive wear of the lining above the tuyeres.

Converters with Bottom Tuyeres.—The first converter with bottom tuyeres was patented by Bessemer in 1857. It had only one tuyere hole in the bottom, through which the blast passed, and when converted, the metal was tapped. A special nozzle gear was made to serve the double purpose. The vessel was suspended in a fixed position. Fig. 52 is a sectional view of the arrangement.

The next development was the giving of rotation to the converter to allow

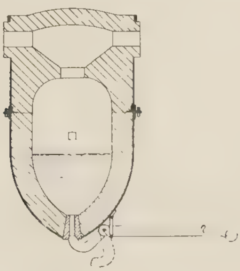


FIG. 52.

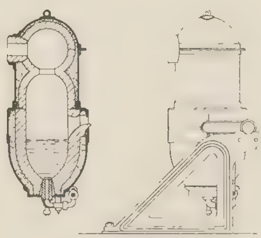


FIG. 53.

the charge to be poured from the side instead of from the bottom of the vessel. A sectional elevation and side elevation of the vessel are shown in Fig. 53.

In Fig. 54, it will be noticed that the pouring and charging hole is near to the top of the vessel and in line with the axis of the rotating shaft to which the converter is attached; the whole being operated with worm gearing.

Fig. 55 shows a modification of the design shown in Fig. 54. When the vessel is turned at right angles to its normal position for blowing, the metal is quite clear of the tuyeres.

In 1858, Bessemer erected in Sheffield a converter of more balanced design, which was an improvement on previous vessels. It is shown in Fig. 56.

Two years later he patented an elaborate arrangement consisting of a revolving structure on which were mounted four converter vessels. Each vessel could be tipped hydraulically, and the whole structure turned round, so that the charging of all the vessels could be done from one place, and the

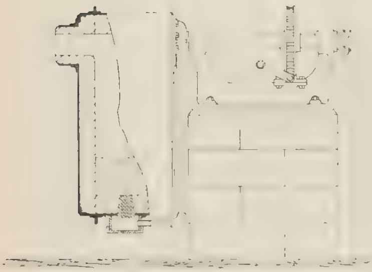


Fig. 54.

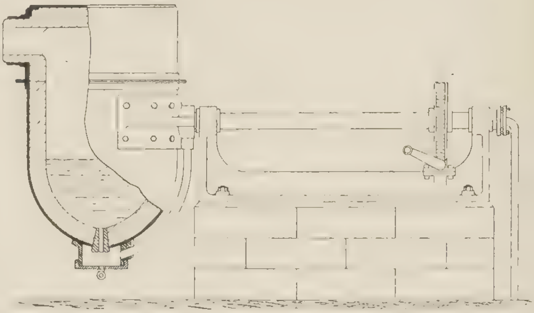


Fig. 55.

"blowing" and casting done from another. The bottoms of the converters were giving trouble, but with 4 converters it was possible, should the bottom of one fail, for another to be brought quickly into use. Fig. 57 is a section of one of the four converters.

Original Ideas Revived.—It would appear that much difficulty was found with the bottom tuyeres, for in 1861 Bessemer patented a converter vessel with

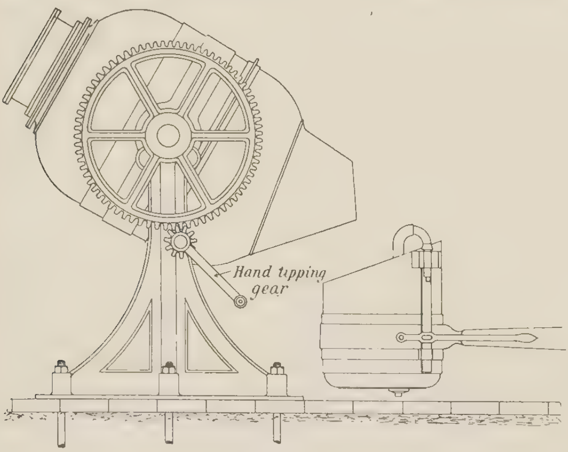


Fig. 56.

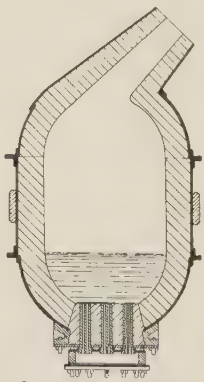


Fig. 57.

a solid bottom, and used a portable tuyere, as shown in Fig. 58. This was simply a revival of his first idea, but with the addition of a built-up tuyere in place of the clay pipe. In his patent he states :—"That the powerful heat generated at or near the orifices of the tuyeres, together with the chemical action of the slags or oxides of iron and silicon, has the effect of enlarging these orifices and in a short time rendering the tuyeres unfit for further use. The tuyeres, when thus worn, have to be replaced by new ones. The fitting in

of these tuyeres, by the plan at present practised, renders it necessary first to knock out the old ones, and then cool down the converting vessel, after which the new tuyeres may be inserted in their places and the spaces around them filled up with a plastic matter or 'grout,' which is generally composed of powdered 'ganister' mixed with water. After this is done, a fire is lighted in the converter vessel and the wet parts thereby properly dried and the interior of the vessel again highly heated before the process of conversion can be repeated, the change

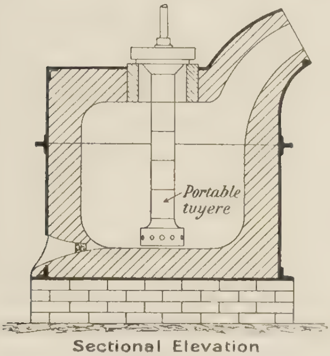


FIG. 58.

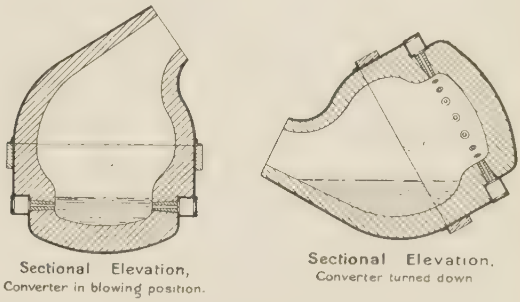


FIG. 59.

of tuyeres thus rendering the apparatus incapable of being used for several hours."

From these remarks, it appears that Bessemer at one time had reached almost a state of despair regarding bottom tuyeres, and had in view the possibility of a return to the use of a vessel with solid bottom. The portable tuyere down which the air passed, was fixed to a cantilever arm raised and lowered by a hydraulic ram. After the operation of blowing, it was lifted from the converter, swung round through 180°, and lowered into a heating pit to keep it hot.

In 1862, Bessemer patented a side-blown rotating converter, shown in Fig. 59, in which the tuyeres were placed through the side all round the bottom of the vessel. The converter was so designed that in the pouring and charging positions the tuyeres were above the level of the metal; both operations could therefore be performed when the blast was shut off. The fixed vessels used in Sweden and Germany were superseded by the rotating converters.

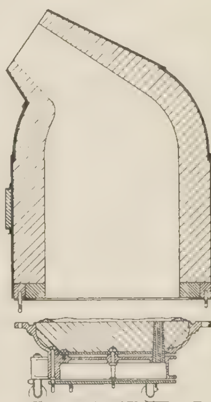


FIG. 60.—Bessemer's detachable bottom.

Detachable Bottoms (Bessemer's).—In 1863, Bessemer patented the first detachable bottoms used with converters in which were fitted the loose tuyeres. It was a step in the right direction, and shortened the time required for making good the bottoms. By using a spare bottom, it was intended to remove the defective one and replace it with a new one so that the work could be proceeded with in a short time. Difficulty, however, was found with the joint between the bottom and the lining of the converter, the repair of which often took some time and caused considerable delay. Fig. 60 shows the detachable bottom used.

The skill and ingenuity exercised by Bessemer are indicative of the marked ability of the man, and his dogged perseverance in spite of so many failures and

difficulties. With the above-mentioned patent he had practically solved the whole of the problems connected with the converter and his process, the difficulty with the detachable bottom, referred to above, being overcome by Holley a few years later. No more striking appreciation of Bessemer's achievements could be expressed than is evinced by the fact that Bessemer converters are, with the exception of minor details, the same as they were 50 years ago, and the process is carried out on the same general principles as were laid down during the first few years of the Bessemer steel-making era.

Detachable Bottoms (Holley's).—In 1868, A. L. Holley and Pearse of Pennsylvania, U.S.A., patented a detachable bottom and also moulds for rapidly repairing the lining of the vessel and the bottoms.

The mould for repairing the lining at the bottom joint of the converter was in the form of a cone, and was fixed to the vessel when the bottom was removed. The top of the body of the converter was detached so that ganister could be rammed in between the mould and the surrounding lining without the men going inside the vessel. Repairs could thereby be speedily effected.

The mould used for ramming the bottoms produced a male joint, which fitted

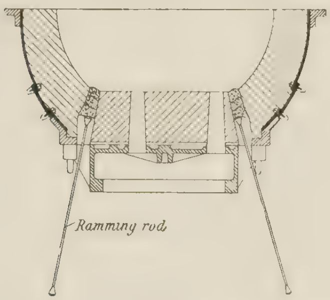
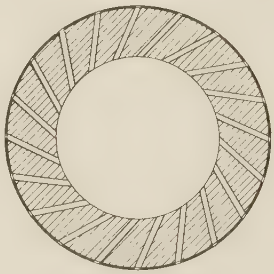


FIG. 61.—Holley's detachable bottom.



Section through tuyeres.

FIG. 62.—Swedish Converter.

into the bottom of the converter body, thus making a very satisfactory joint between the latter and the bottom.

Fig. 61 shows an improvement in making the joints of detachable bottoms. This was patented by Alex. L. Holley in 1870, and marked a distinct improvement over his previous patent. Instead of making the bottom joint from the inside, necessitating the removal of the top portion of the converter, the new bottom could be fixed in position, and the joint between it and the lining of the converter rammed from the outside without any discomfort to the men, and at the same time making a most satisfactory joint without causing serious delay.

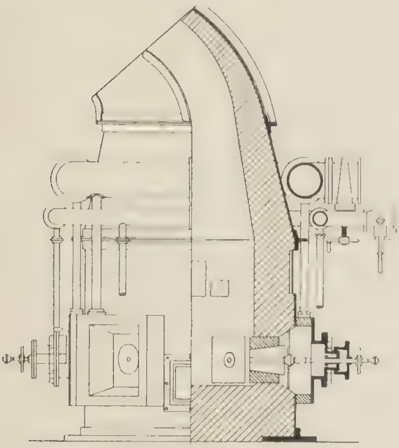
Small Side-blown Converters.—Although Bessemer patented the rotating converter with side-blown tuyeres in 1862, the fixed converters continued to be used in Sweden and Germany for many years. Fig. 62 shows a section through the tuyeres of one of these fixed converters. It was necessary with the early form of Swedish fixed converters to continue the blast until most of the metal was tapped from the converters, otherwise the metal went back into the tuyere box. To tap the metal before the carbon was completely reduced, gave rise to irregular qualities of steel, and to wait until the end of the blow before tapping and continue the full blast or partial blast during the "tap," led to overblown steel.

In this country, in America, and on the Continent, attempts were made to overcome this difficulty, the results of which are as follows:—

Witthöfft Converter.—This was of the fixed type, and similar to the Swedish

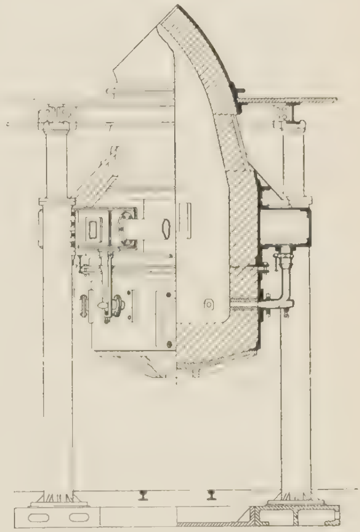
converter, but the tuyeres were inclined to the horizontal, as well as placed so that the ends of the tuyeres in the blast-box were above the level of the metal in the converter. There were 4 tuyeres instead of the usual 20. This converter was abandoned because of the rapid wear of the tuyeres.

Clapp & Griffiths Converter.—Fig. 63 illustrates this converter, the important features of which consisted of an arrangement whereby the tuyeres and slag-hole could be closed at the end of the blow and the tap-hole immediately opened. The tuyeres were 6 in number, each having one hole $1\frac{1}{8}$ inches in diameter, and, while placed horizontally and radially, they were also about 8 inches above the bottom of the converter, so that when half the metal was tapped, the valves used for closing the tuyeres could be opened and the blast shut off, while the remainder of the steel was tapped from the converter.



Half Sectional Elevation

FIG. 63.—The Clapp and Griffiths Converter.



Half Sectional Elevation

FIG. 64.—The Hatton Converter.

These converters worked very satisfactorily, it being recorded that as many as 20 heats of steel per shift were obtained from the converter without difficulty. The pressure of the air used was from 7 to 10 lbs. per square inch. The tuyeres had to be renewed every 20 to 40 heats. Repairs to the mouth of the vessel were also frequent, the practice being to work one vessel for the first half of the week and then shut it down for repairs, while another vessel was put in operation for the remainder of the week.

Hatton Converter.—In this converter, which was patented in 1883 and illustrated in Fig. 64, the principal improvement is found in the use of a valve on the blast pipe leading to each tuyere, which is partially closed at the moment of tapping. The complicated differential pistons and stopper valves in the Clapp and Griffiths type are dispensed with. The blast box is above instead of on the level with the tuyeres, allowing for repairs to be effected more easily. A detachable bottom is also used, making its renewal easy after from 50 to 80 heats of steel have been produced.

Witherow Converter.—In 1885, Witherow patented a converter shown in Fig. 65, in which the same effect was produced by one valve as was obtained by the six valves in Hatton's design. The object was the same, *i.e.* to reduce the blast pressure at the end of the blow. It will be observed from the figure that one pipe is connected with the blast box, and upon this pipe is placed the

regulating valve. It was certainly an improvement. Three blows per hour were obtained from this vessel. With two converters, in which alternate heats were blown, four heats each of $2\frac{1}{2}$ tons could be obtained per hour, and as many as 150 tons in 24 hours.

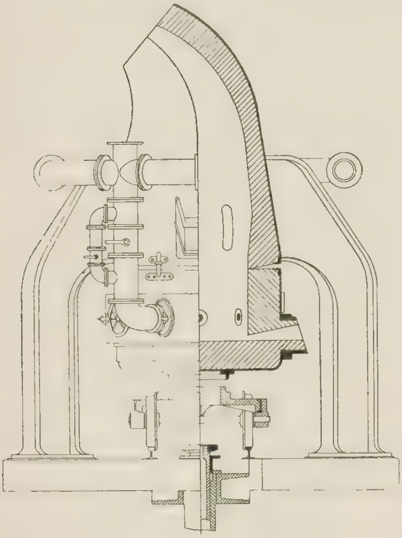
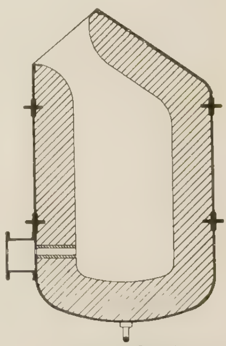


FIG. 65.—The Witherow Converter.

Walrand Converter.—In this design there was a distinct departure from the other converters already mentioned. It will be noticed from the illustration, Fig. 66, that the tuyeres are on one side only, although in his patent specification, dated 1884, he shows a vessel of circular section as in Fig. 67, with tuyeres extending three-fourths round the circumference. Hitherto the tuyeres had been placed all round circumference at the extreme bottom, or halfway from the bottom to the surface of the charge.

Walrand placed the four tuyeres on one side close together, but slightly inclined them from the centre to give rotation to the liquid metal. They were also placed nearer to the surface than before. This appeared a retrograde step, as it had always been contended that the nearer the blast approached to the surface the greater was the waste due to oxidisation. This, however, was not found to be the case. There was no difficulty to overcome regarding the possibility of the metal getting into the tuyeres when the blast was shut off, as the converter was mounted on trunnions and could be tipped in the ordinary manner. Each of the four tuyeres had a rectangular hole, $3\frac{1}{2}''$ to $4'' \times 1\frac{1}{4}''$, and with a 1-ton charge both acid and basic steel were made successfully.

The waste in the acid steel averaged 16 per cent., which was not any more than in the fixed converter with tuyeres above the bottom. The original Swedish vessels (fixed) with tuyeres at and round the bottom produced a waste of from 12 to 15 per cent. The time taken to blow was from 16 to 18 minutes with a pressure of from 4 to 5 lbs. per square inch. When blowing basic charges, a slightly lower pressure was required, and the blow lasted from 6 to 12 minutes for a 1-ton heat; 2 to 3 charges were produced per hour.



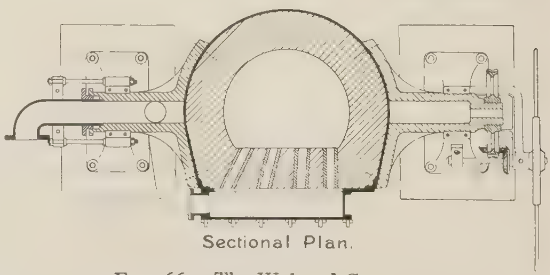


FIG. 66.—The Walrand Converter.

Robert Converter.—The cross-sectional drawing of the Robert converter shown in Fig. 68 is so much like the Walrand that it is difficult to see the ground for a patent in

1887. Robert introduces more tuyeres, each having holes of different section than in the Walrand converter. He also defines a definite angle for each tuyere, ranging from 0° to 20° to the perpendicular. Another point of difference lies

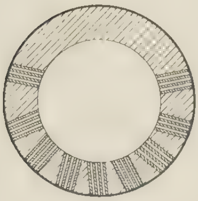


FIG. 67.—The Walrand Converter.

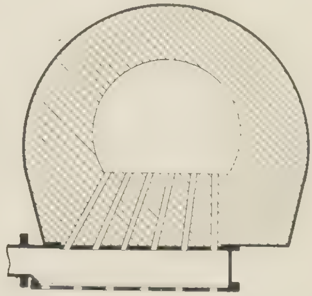


FIG. 68.—The Robert Converter.

in the tuyeres being placed nearer the surface of the metal in the converter than in the Walrand, the distance being about $1\frac{1}{2}$ inches instead of $3\frac{1}{2}$ inches. Robert claims that by having the tuyeres near the surface the reaction takes place at once when the blast is blown down into the liquid metal, whereby the products of the reaction mix immediately with the slag instead of passing through the body of metal.

Tropenas Converter.—From the history of the side-blown converter it will be observed that the original Swedish fixed converters had tuyeres at the bottom; gradually the tuyeres were raised towards the surface until in the case of the Tropenas design, sections of which are shown in Fig. 69, the blast is directed upon the surface, from the side of the converter.

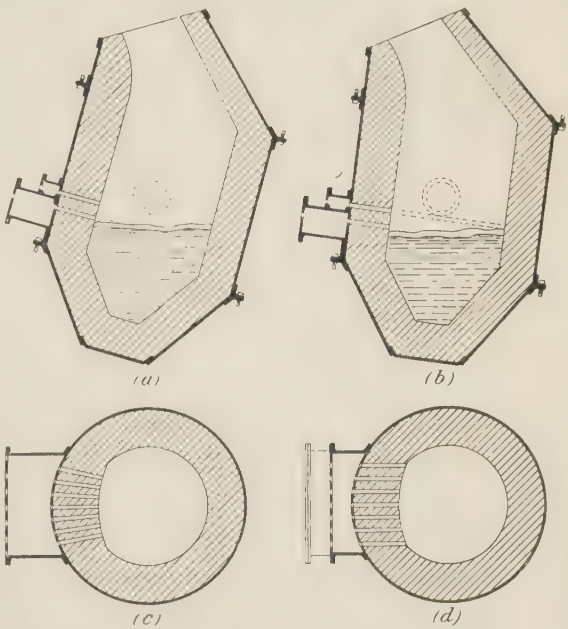


FIG. 69.—Tropenas Converter.

(*a*) Blowing position. Bottom tuyeres in action.
(*b*) ,, ,, Top ,, ,,
(*c*) Section through bottom tuyeres.
(*d*) ,, ,, top ,,

Tropenas made a distinct development in the process of converting iron into steel, and proved that it was unnecessary to have a violent swirling action of the metal in the converter, which had hitherto been considered essential. Fig. 69, *a*, *b*, *c*, and *d*, shows sectional elevations and plans of this converter, showing the relative positions of the tuyeres to the surface of

the metal. In his patent of 1891, he shows two rows of tuyeres, and claims thereby "a method of increasing the temperature within the converter by projecting air through tuyeres arranged at a sufficient height for causing combustion of CO and hydrogen evolved during the operation." It is many years since it was found quite unnecessary to have the top row of tuyeres.

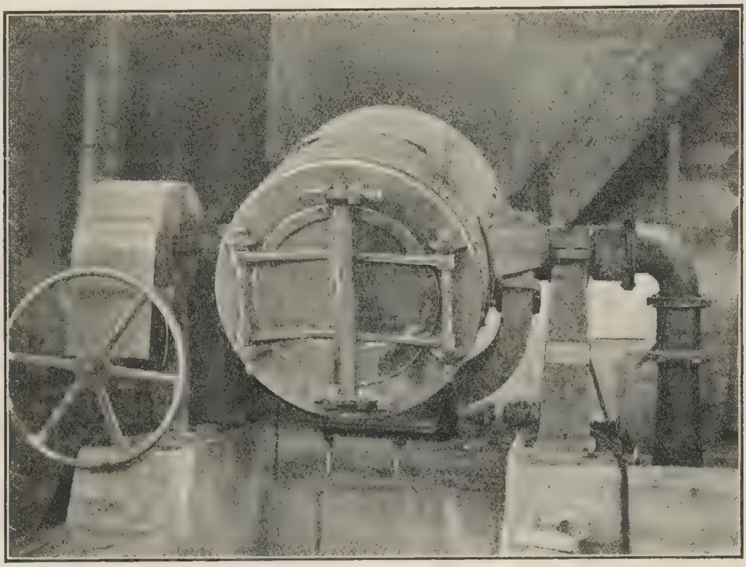


FIG. 70.—Tropenas Drop-Bottom Converter.

Drop-Bottom Converters.—Tropenas has recently applied "drop-bottoms" to small converters, on the same lines as they are used at present on cupolas. There are two hinged parts forming the door, and when closed a bar is placed

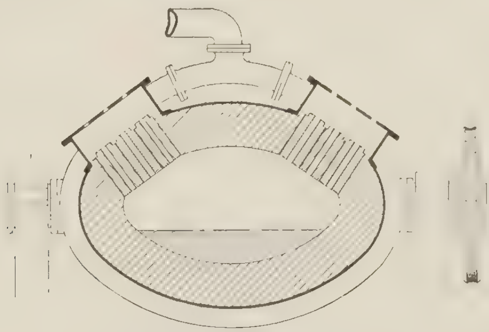


FIG. 71.—The Stock Converter.

across the middle of them and secured to the bottom with suitable clamps. Fig. 70 shows the bottom clamped in position.

When the "blowing" is done each day the doors are opened and the bottom knocked out. This allows much more rapid cooling, making it possible to do

the patching next morning before starting another day's work. To make a fresh bottom, the doors are closed, and a special composition is rammed upon them, which is dried quickly by the usual heating, preparatory to receiving hot metal. With this arrangement it is possible to work the same converter every day, instead of every alternate day, as is the case with converters having solid bottoms.

Stock Converter.—Fig. 71 shows a section through the lining and tuyeres of the Stock converter as patented in 1908. This vessel is used both for melting and converting the pig iron. Oil jets are placed in the tuyeres during the melting process, which is carried out under a low pressure blast of from $\frac{1}{2}$ to $\frac{3}{4}$ lb. per square inch.

The melting is done while the converter is in a horizontal position, and the hot gases from it pass into a heating chamber through which the blast pipes pass from the blower to the converter, thereby raising the temperature of the air. When the melting is completed the oil jets are removed and the converter set in position for blowing.

The principal advantages of the process are—

1. That no sulphur is introduced during melting.
2. The waste heat from the melting is utilised for heating the blast.

CHAPTER XV

LARGE BESSEMER CONVERTER PLANTS

In Chapter XIV, on the evolution of the Bessemer Converter, reference has been made to the development of the bottom-blown converters which belong to the class, designated large, in contradistinction to the small Bessemer plants, which are commonly made of the side or surface-blown types. There are, of course, some small bottom-blown plants of 2 tons capacity, but these are almost invariably used for the manufacture of steel for castings, and not for ingots such as are produced in the larger plants. The equipment of large Bessemer plants is necessarily on a very much larger scale than that of the side or surface-blown plants. Most of the large plants work in conjunction with blast furnaces direct, or indirectly with them through mixers. (It is also a common practice in some works to remelt pig iron in cupolas before converting the metal into steel.) The size of converters has been increased from time to time, until now they are made with capacities up to 30 to 35 tons.

Basic- and acid-lined converters differ principally one from the other in the kind of lining used. In the design, general arrangement, and mechanical features, these two kinds of converter plants are not necessarily unlike each other. The basic-lined converter is usually larger than the acid-lined converter of the same capacity, to allow for the use of lime and oxides in the former, but with this exception, both plants can be made practically identical.

Design and General Arrangement of Bessemer Plants.—The locality and situation of the works, and the relation of the Bessemer converters to blast furnaces (if any) and the mills, also the size of the converters, influence very considerably both the general design and arrangement of the plant. Bessemer converters for the production of ingots vary in capacity from 5 to 35 tons; some plants for this purpose may be still at work having capacities below 5 tons. In the case of large plants, the auxiliary machinery required for handling raw materials and the liquid metal must be necessarily of far more ample proportions than that required for smaller installations.

Cupolas.—In addition to the cupolas which are used for melting spiegeleisen, such as are shown in Fig. 87, large cupolas for remelting the pig iron are employed, where the molten metal cannot be taken direct from the blast furnace or mixer to the converter. These cupolas differ in details of design in several particulars. With reference to the bottoms, some are solid with wells of varying capacity, from which the metal is tapped as required, just as in smaller cupolas; while others have bottoms which serve the same purpose as drop-bottoms, but are arranged on removable trucks.

Fig. 72 shows a sectional elevation and plan of a typical cupola with solid bottom, as used at the Burbach Steel Works in Germany. The metal is tapped into a ladle on a loco wagon below, while the slag is run into slag pans on loco trucks.

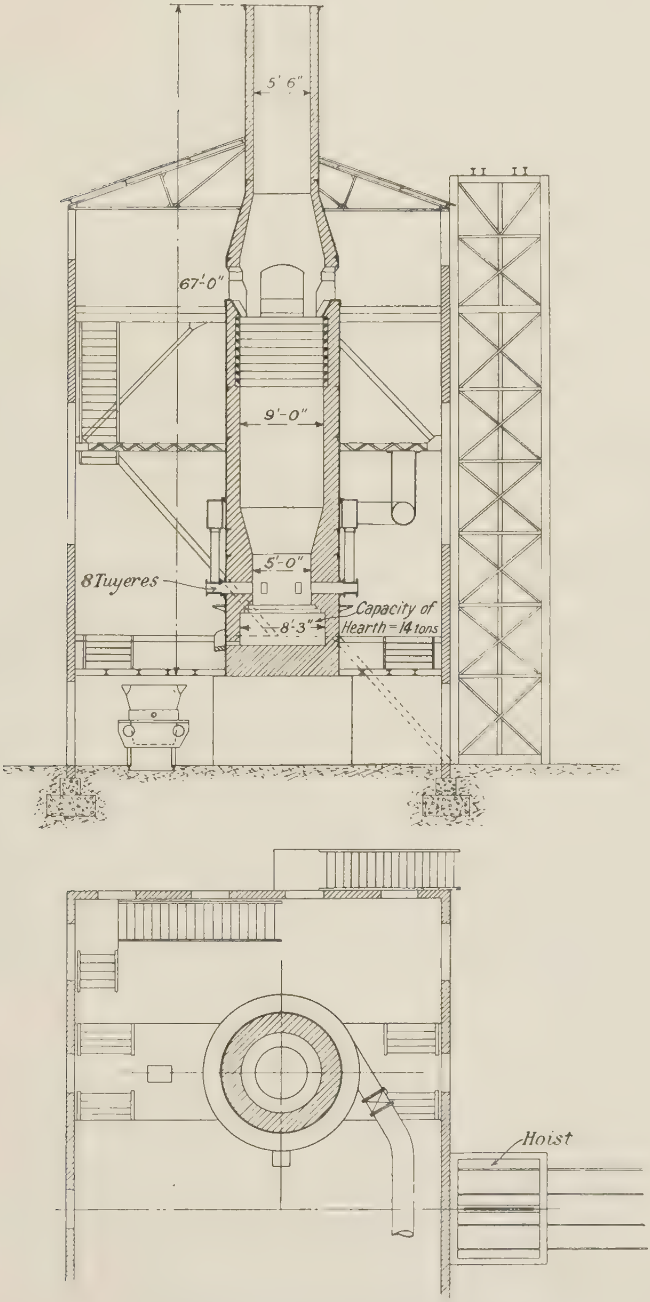


FIG. 72.—Cupola at Burbach Steel Works, Germany.

Mechanical Charging of Cupolas.—Many devices are employed for mechanically charging large cupolas. In some works all the materials, such as pig iron, scrap, coke, and limestone, are conveyed in skip trucks along elevated conveyors to the top of the cupolas, into which the materials are tipped automatically. The arrangement of charging is usually determined according to the conditions available for handling materials and the cost of labour in the locality.

When the pig iron and scrap metal are brought into the works in railway trucks and unloaded in the stock yard by overhead travellers with electro-magnets, the storage of the iron in stacks, suitably arranged for the loading of

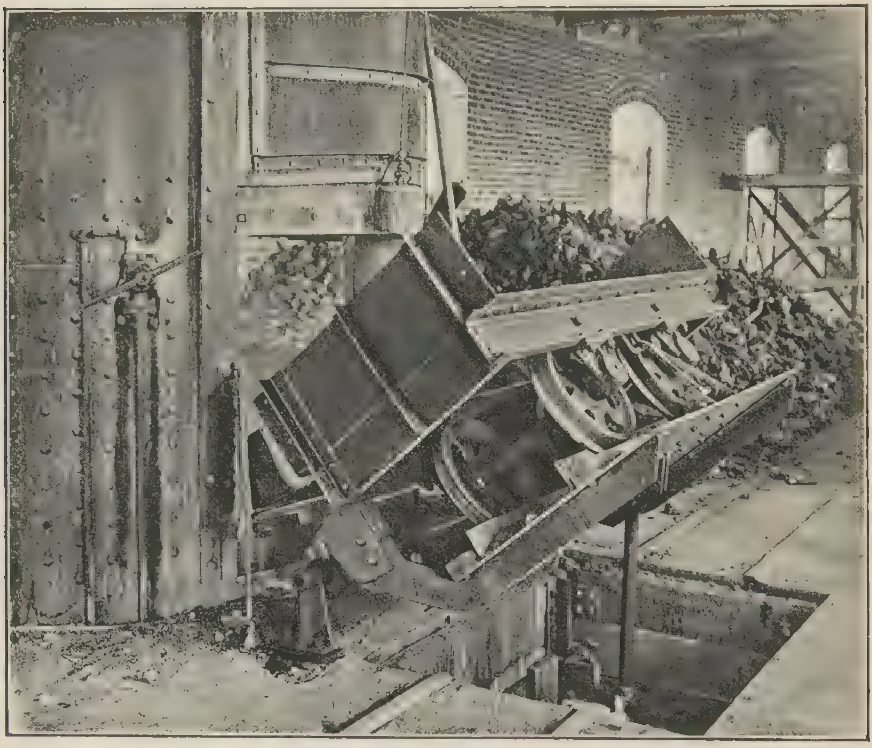


FIG. 73.—The Whiting Cupola Charging Machine.

narrow-gauge charging trucks, is usually carefully observed. These trucks are loaded by an electric overhead crane, fitted with electro-magnets, and are either brought direct to the charging platform of the cupola and tipped so that the contents are shot into the cupola, or elevated from a lower floor to the charging stage, and tipped automatically, thus discharging the materials into the cupolas.

The means of tipping employed are numerous, and the power for operating the tipping devices may be steam, air, water, or electricity. In America such devices are more common than in this country. Fig. 73 shows a photograph of a Whiting Charging Machine in the tipping position. The trucks, it will be observed, are of simple design. When charging pig iron and scrap they have end plates only, about 12 inches high, with open sides; but when used for carrying coke they are fitted with sides hinged from the top. At the side of the

cupola and near the charging door is fixed the hydraulic valve for operating the tipping cylinder. A different type of charger is shown in Fig. 74, in which the truck of material is elevated by an electric hoist, it being so designed that as the truck is raised vertically, the platform on which it stands is also tipped automatically.

Objection is sometimes taken to mechanical charging, because of the possibility of uneven distribution of the material charged into the cupola. This, however, can be regulated by the operator, a sudden movement of the tipper causing the materials to be discharged to the far side, and a slow movement to the near side, of the cupola.

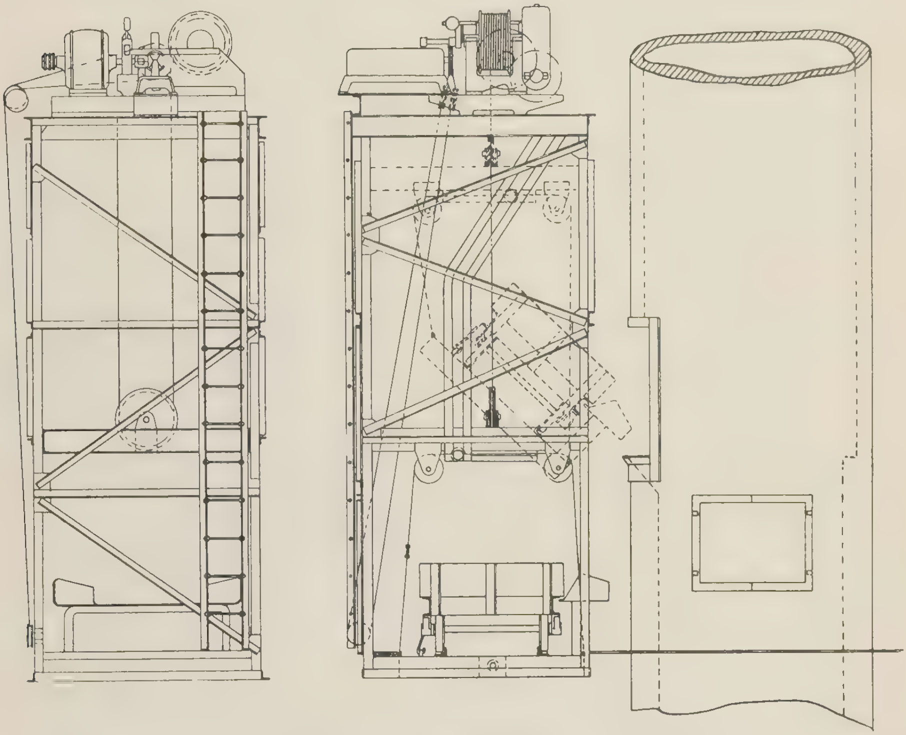


FIG. 74.—Whiting Electric Charging Machine for large Cupolas.

There can be no question that the mechanical charger has been successfully employed as a means of saving labour. For instance, two men can attend to the entire charging operations on the stage of a cupola melting 20 tons of metal per hour when equipped with efficient charging apparatus. The same cupola would require 5 or 6 men to produce the same results by hand.

Converters.—As far as the design of the converter is concerned, its form is usually similar, both in large and small sizes, the chief characteristics of a good converter being a cylindrical body with conical concentric nose and detachable bottom. In the heavier designs the bodies are usually made in 3 or 4 sections—the nose part, the body section, and the bottom. Fig. 75 shows a typical design. Many large converters are made with the nose part eccentric with the body, as most of the older types of converters were made. There are certain advantages in using converters with eccentric nose parts, as shown in Plate II

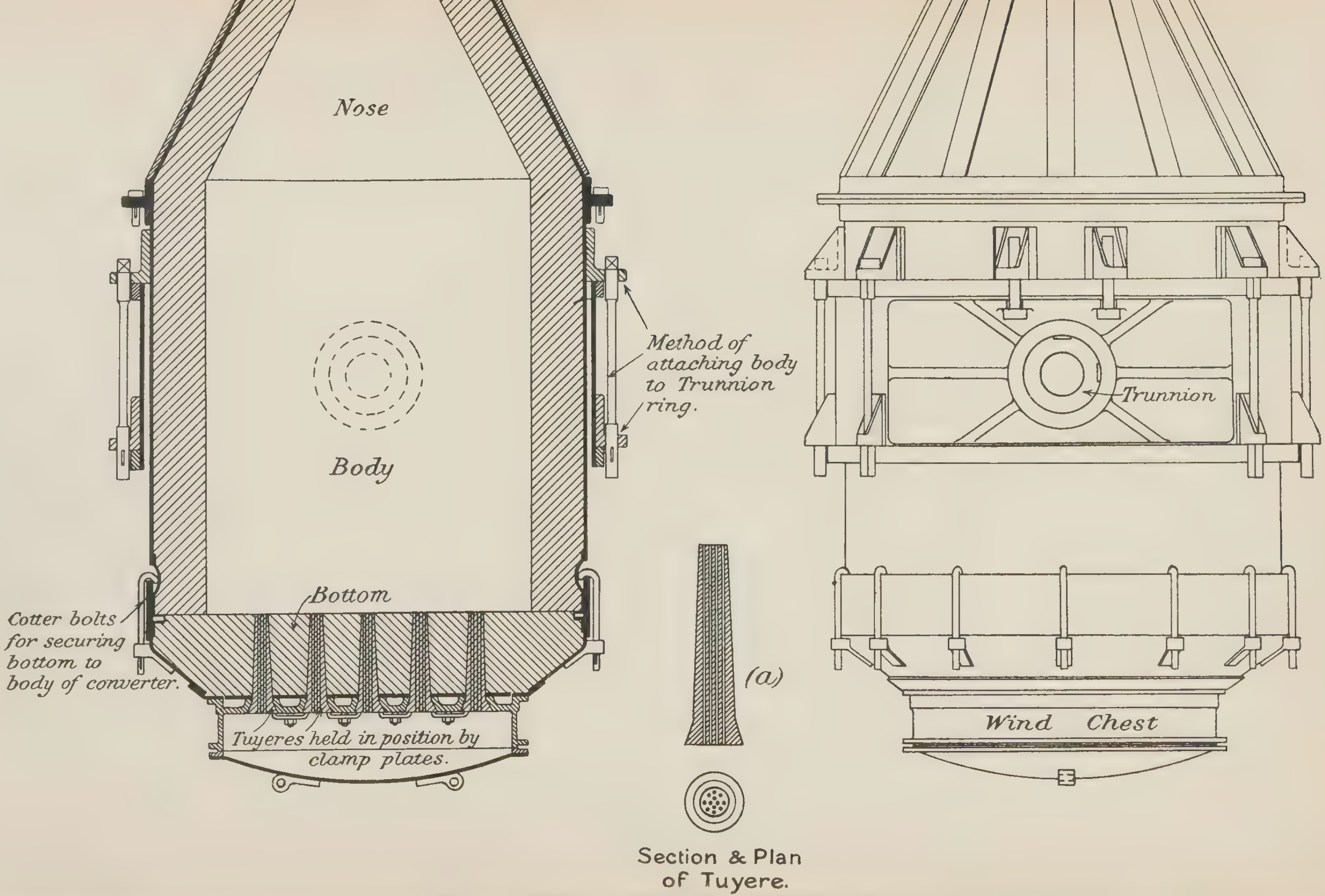


FIG. 75.—Modern Converter with Concentric Nose.

(opposite p. 160), the principal being (1) that the gases and slags issuing from the converter can be carried away more easily, and also cause less inconvenience in operating the overhead plant than when the gases, etc., issue from the converter in a vertical direction; (2) the charge can lie in the body of the converter with less risk of entering the tuyeres or escaping at the nose when the blast is shut off. The view of the tuyere block inside the converter is, however, restricted when the converter is made with an eccentric nose.

Converter Bottoms.—Detachable bottom sections are now universally employed with converters. They usually consist of the wind chest, combined with suitable attachments for fastening to the converter shell and for retaining the refractory bottom. In Fig. 75 is shown two views of a typical converter, which is built up in 3 sections, the bottom being attached to the body by means of cotter bolts.

Another type of converter body with detachable bottom is illustrated in Fig. 76. In this design the bottom is fixed to the body of the converter with bolts and cotters, arranged differently from those shown in Fig. 75. The design shown in Fig. 76 represents the converters used at the Burbach Steel Works, in which a ring is fitted between the wind chest and the shell of the converter, to prevent the wind chest from being damaged should a leakage of steel take place at the bottom joint.

There are two distinct kinds of refractory bottoms:—

1. Refractory blocks with holes in them, to receive fireclay tuyeres.
2. Refractory blocks through which the blast holes are pierced while the bottom is being rammed, no other tuyeres being used.

In Fig. 75 is shown a completely rammed and tuyered bottom in position. It is composed of refractory material fitted with fireclay tuyeres as shown at "*a*." The tuyeres are kept in position by means of plates and bolts fixed to the under face of the plate on which the bottom is rammed. The method of fixing the tuyeres is shown in the illustration.

Referring to Fig. 76, section of converter, it will be observed that the refractory bottom or block is pierced with small holes about $\frac{5}{8}''$ diam, instead of being fitted with fireclay tuyeres. The refractory block is rammed upon a perforated iron plate in a machine specially designed for this purpose, such as is illustrated in Fig. 89, p. 166. After being dried, the block is secured in the base of the converter by screwed studs which pass through bars of mild steel supported in recesses in the wind chest frame. These are shown at "A" in Fig. 76. These refractory blocks are removed from and replaced in the converter, by specially arranged hydraulic ram mounted upon a truck, without disturbing more than the cover of the wind chest and the screwed studs referred to above. It is, therefore, found unnecessary to break the joint between the wind chest and shell of the converter when fitting new tuyere blocks.

Tilting the Converter.—The method employed for tilting is either with the rack and pinion as shown in Fig. 77, or with worm and wormwheel as usually adopted with the smaller converters. In the former case the pinion is securely fixed to the trunnion on one side of the vessel, and the rack which engages with it and forms part of a piston in the hydraulic cylinder, is kept in gear by a guide, against which the rack slides when pressure is admitted to the cylinder. The operation of the worm and wormwheel attachment is either controlled by a separate steam engine or electric motor, the wormwheel being keyed to one of the converter trunnions. The hydraulic tipping gear is most commonly adopted for large plants. Both designs are suitably protected from dust and falling slag by sheet steel covers.

Trunnion Bearings.—Special attention has been given to the design of trunnion bearings. In some cases the lubricant is forced into them under high

pressure while the vessel is in motion only, and by means of the movement of the converter. A very liberal supply of grease is also kept in the bearing covers to prevent abnormal friction, should the automatic lubrication from any cause

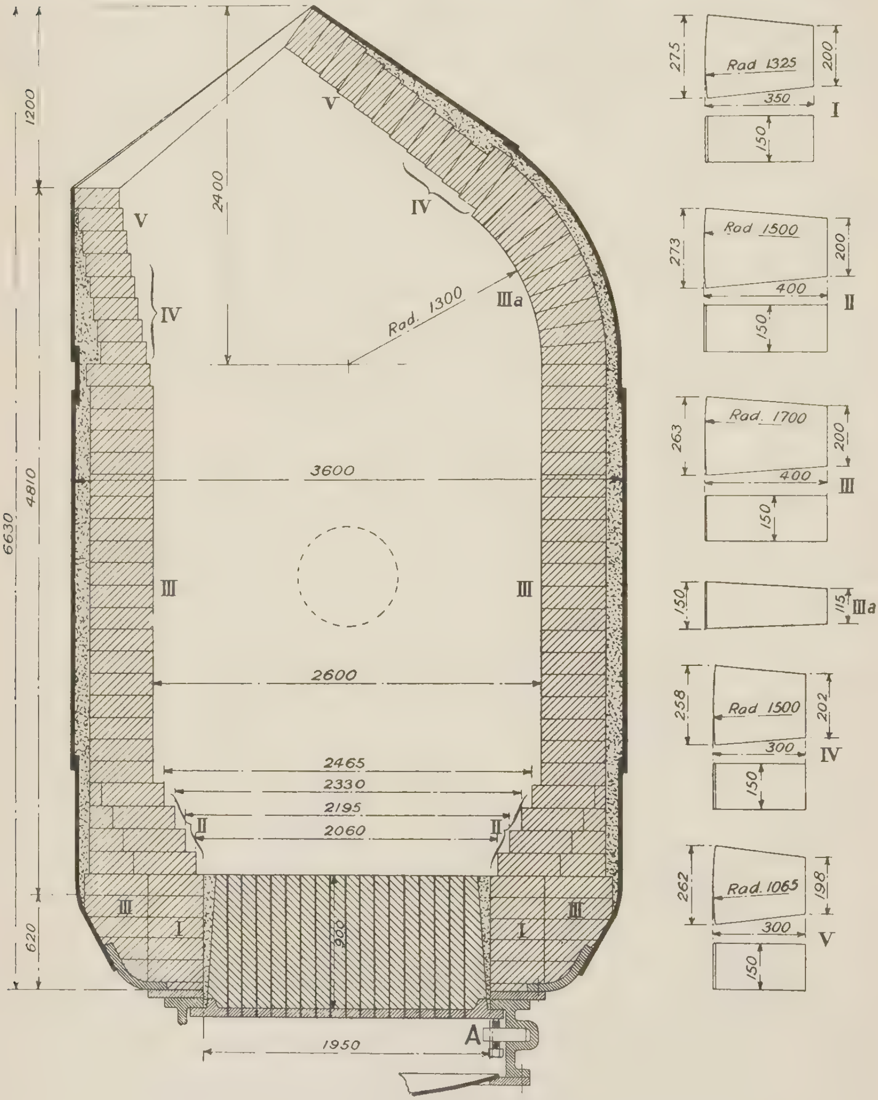


FIG. 76.—Section of Converter used at Burbach Steel Works.
(NOTE.—All dimensions are in millimetres.)

whatever fail to act. Roller bearings of various forms are also used, in which the movement of the trunnions causes the rollers to turn in thick oil. Lateral clearance on trunnion bearings is always allowed, for expansion and contraction of the converter.

Operating Valves.—The operating valves, including the blast and tilting valves, are arranged as a rule on a platform close by the converter and in such a position as to allow the man in charge to have a full view of the converter in all positions. Here also are fitted the signalling apparatus to the blast engine house, the pressure gauges from the blast and hydraulic mains, and other signalling appliances to the mixers, cupolas, heating furnace, and charging platforms.

Non-Return and Relief Valve.—As near to the stop valve as possible, and on the converter side of same, is fitted a non-return valve which automatically closes when the pressure is shut off, preventing the return of any explosive gases to the blast mains. A relief valve is also fitted in conjunction with the blast stop valve, so that the operation of the one is dependent upon the other. Such valves are also capable of working independently of the blast valves, and can be weighted to relieve pressure according as required. Relief valves are fitted on

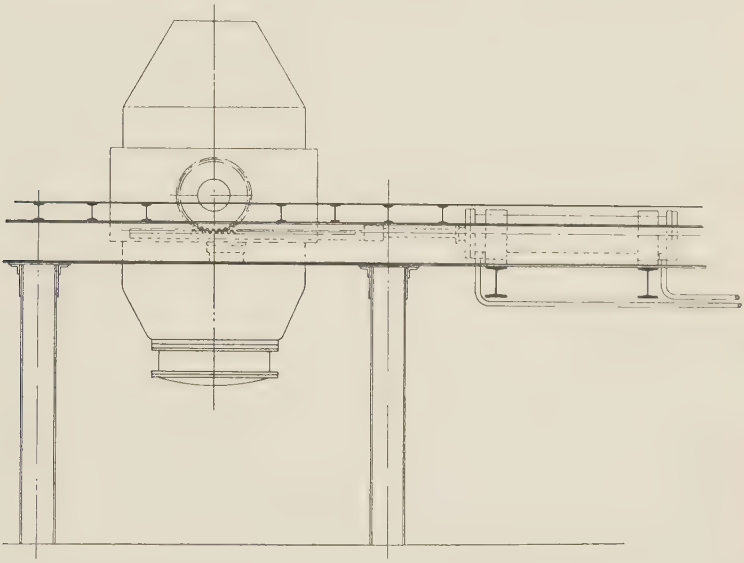


FIG. 77.—One method of Tilting Converter, with Hydraulic Ram arranged horizontally.

the blast mains in some designs quite independent of the blast valves, but in all cases operate automatically.

Blowing Engines.—There are many types of blast engines for supplying blast to the converter. In works where blast furnace gas can be utilised economically, gas driven blowing engines are used. In other works, electrically driven blowing engines are employed, while the older form of reciprocating steam engine of the vertical and horizontal types are more frequently installed. Steam-turbine driven blowing engines also find favour in some works. In Chapter XVI a few modern blast engines are described, illustrated, and compared.

Arrangement of Converters in Relation to Other Plant.—The most general arrangement of converters is to erect them side by side in one line, each being mounted in standards above the casting shop level with the bottom of the converter sufficiently high to admit of its detachment from the body and removal on specially designed trucks, with the minimum of labour. The relative position of the mixers, blast furnaces, or cupolas for remelting pig iron, and the cupolas

for spiegel, have a determining influence upon the character and arrangement of the staging, buildings, and superstructure of the plant. In some works where there are no blast furnaces, all the pig iron used in the converters is remelted in cupolas, while in other works, cupolas are only used for melting the pig iron produced from the blast furnaces during the week-end. In other cases the cupolas are not used at all, as the metal from the blast furnaces at the week-end is passed through the mixer before being transferred to the converter. Most of the largest works employ the mixer, into which all the metal from the blast furnace is poured, and from which the converters are supplied. Different types of mixers are described in Chapter XXX.

Auxiliary Equipment.—The auxiliary equipment for Bessemer plants differs according to the design and general arrangement of the installation, and the facilities available for handling the materials. Much labour and ingenuity have been bestowed on the design of the appliances used in various works for handling the materials, as well as in adequately dealing with the repairs of the vessels and other parts of the plant. The crushing, grinding, mixing, stamping, and drying machinery and furnaces for the refractory materials used in the converters, are in themselves of considerable importance in large works, the design and arrangement of which have required careful study. Many other designs and arrangements of plants could be given, but the following descriptions and illustrations of typical British, American, and German Bessemer plants, afford a more comprehensive idea of the characteristic features of the general Bessemer practice throughout the world.

British Bessemer Practice

British Bessemer practice has been very largely confined to the acid Bessemer process, and unfortunately the progress, as far as output is concerned, has been declining during the past 20 years, as will be observed from the following :—

Output of Acid Bessemer Steel

1890 . . .	1,612,730 tons of ingots.
1900 . . .	1,253,903 „ „
1910 . . .	1,138,103 „ „

The production of basic Bessemer steel in this country is relatively small, and the increase in the rate of output during the pass few years is not comparable with that of Germany. In 1880, Great Britain produced 10,000 tons of basic Bessemer steel, and during the same year Germany's output was 18,000 tons. In 1910 (30 years later) the outputs were as follows :—

Great Britain	641,012 tons.
Germany	8,030,571 „

Table LV shows the output of acid and basic Bessemer steel ingots in Great Britain during the past 30 years compared with the open-hearth steel produced during the same period. It will be observed from the table that since 1890 the output of acid Bessemer steel ingots has declined, while that of basic Bessemer steel ingots has increased. The greatest increase has been made with the basic open-hearth steel ingots, the output being over 15 times greater in 1910 than in 1890.

TABLE LV

OUTPUT OF ACID AND BASIC BESSEMER STEEL INGOTS[1] IN GREAT BRITAIN FROM 1880 TO 1910, COMPARED WITH OUTPUT OF ACID AND BASIC OPEN-HEARTH STEEL INGOTS DURING THE SAME PERIOD

	1880	1890	1900	1910
Acid Bessemer	1,034,382	1,612,730	1,253,903	1,138,103
Basic ,,	10,000	402,113	491,104	641,012
Acid open-hearth	251,000	1,462,913	2,862,566	2,653,033
Basic ,, ,,	Not classified	101,287	293,485	1,578,536

There are several basic, but many more acid Bessemer plants in this country producing steel ingots, the arrangement and design of which differ only in details. Some makers use metal direct from the blast furnaces after passing it through mixers, others have the pig iron remelted in cupolas: the plant arrangement differs therefore in the appliances used for handling the materials.

At the works of the North Eastern Steel Co., Ltd., Middlesbrough, the basic Bessemer practice as carried out there may be taken as typical of the best British practice. The works were erected in 1883, and in the following year a description of the plant was given by Dr. Cooper[2] in the Proceedings of the Iron and Steel Institute. Since then, however, the use of cupolas for melting the pig iron has been discontinued, and in other details the plant has been modernised.

10-*ton Converter Plant at the North-Eastern Steel Works.*

General Arrangement of Plant.—From the plan of the North Eastern Steel Works, shown in Fig. 78, the positions of the blast furnaces, mixers, and converters are indicated. The blast furnaces are on one side of the main railway, and opposite to the steelworks where the mixers are placed. The molten metal is taken to the mixers in ladles of 30 tons capacity of the Dewhurst locomotive type, similar to that shown in Fig. 79, and the contents are charged into the mixer with a special form of hydraulic crane for tilting the ladle. There are two 150-ton mixers, and two mixers each of 400 tons capacity. The latter are gas-fired, and since their introduction, the pig iron made by the blast furnaces during the week-end has gone to the mixers instead of being remelted in cupolas as formerly. The mixer houses are conveniently situated in relation to the Bessemer plant, although not adjoining same. They are equipped with modern devices for handling the various materials, such as scrap, ore, lime, fluorspar, etc., which are charged into the mixers by an electric machine. Fig. 80 is a photograph of the mixer stage. From the mixer the molten metal is taken in a locomotive ladle to the converter house, where the ladle of metal is raised to the converter platform by a 20-ton hydraulic hoist, and then taken by a locomotive to the converter, into which the contents are poured.

Converters.—There are four converters arranged side by side, each of 10 tons capacity, three of which are in constant use, while one is always under repair. Fig. 81 shows a photograph of the Bessemer shop. The converters are mounted on standards fixed to foundations on the casting shop level, so that the bottom of each converter is a sufficient height above the ground level to allow of the use of a special truck with hydraulically operated table for the removal of the converter sections. The converters are made in sections for

[1] "Journal Iron and Steel Institute," 1912, I, pp. 48, 49. [2] *Ibid.*, 1884, II, p. 407.

convenience in handling and relining. When the latter is necessary, the special truck referred to is placed under the converter while the nose is upwards and the body is in an upright position. The weight of the bottom section is taken

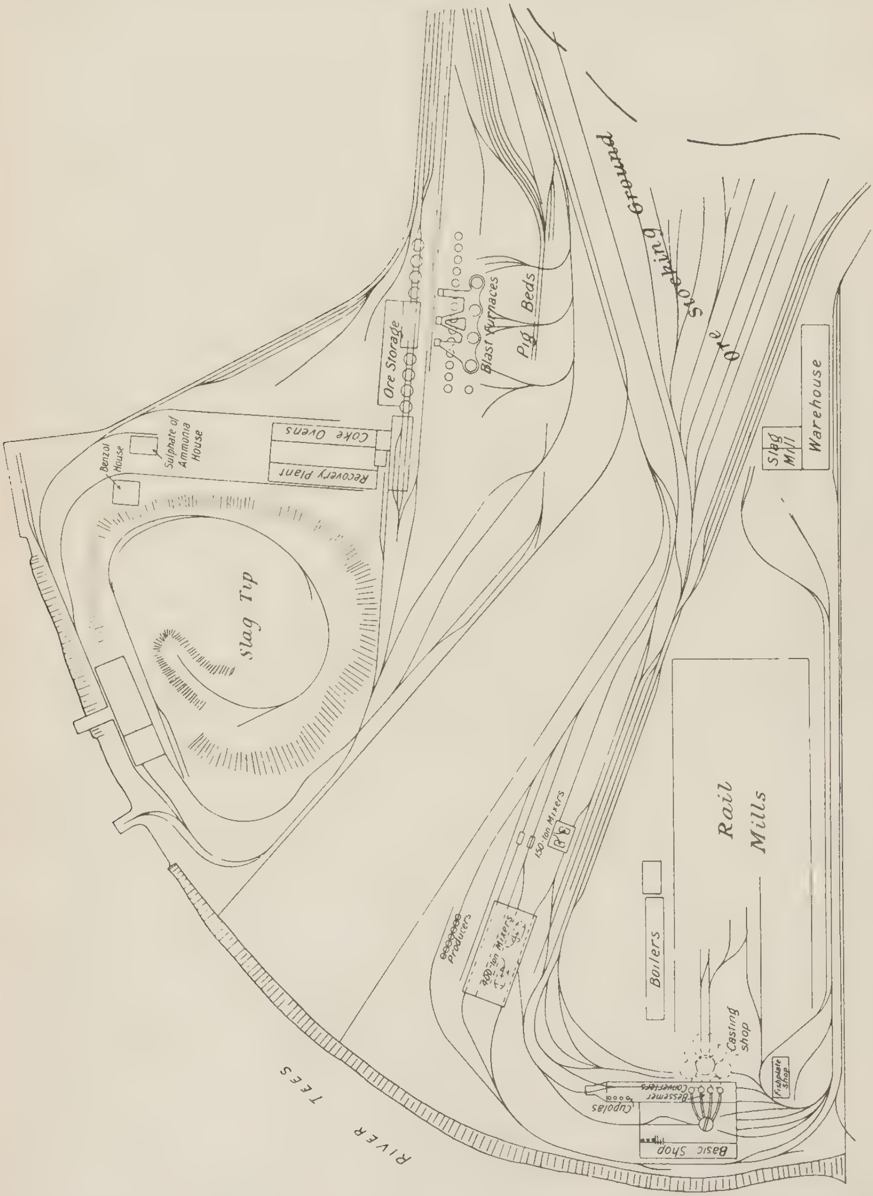


FIG. 78.—Plan of the North-Eastern Steel Works, Middlesbrough.

by the truck while the bolts are withdrawn, after which the table is lowered and the bottom removed on the truck to the repairing shop. From the truck the bottom is lifted by a 30-ton overhead crane and placed on suitable supports, and the old lining knocked out.

The nose and upper portions of the converter are dismantled as follows:—After the bottom has been removed as described above, the converter is turned round with the nose part downwards, under which a truck of a different form to that mentioned above is placed, and into which the nose of the converter fits. An overhead hydraulic crane of 100 tons capacity is used for raising slightly the top part of the converter, and holding it until the bolts are loosened from the trunnion ring, after which it is lowered upon the truck below. This part is now taken away to have the old lining knocked out and the new one put in. A railway turntable admits of trucks being switched into three different repairing roads.

Relining Converters.—The operation of relining consists of bricking the inside of the converter with specially shaped bricks made from dolomite, which

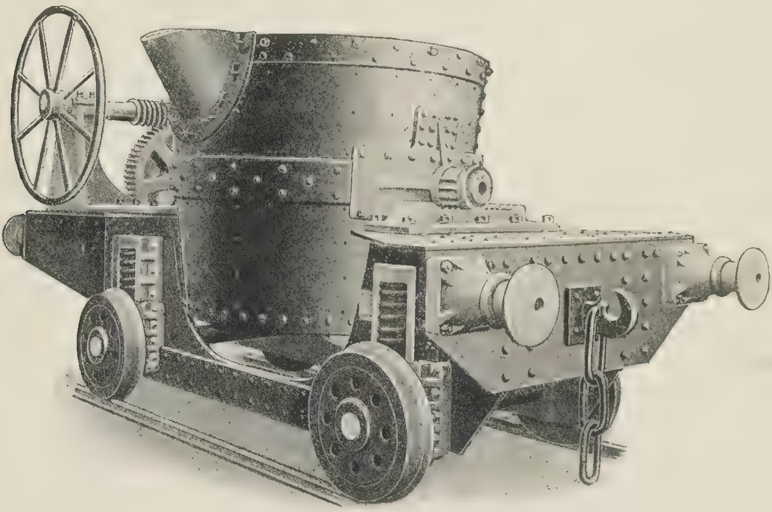


FIG. 79.—Dewhurst Locomotive Ladle.

is roasted, ground, mixed, and pressed into bricks and dried by the North-Eastern Steel Co.'s own plant in the basic repair shop. The converter is placed on a stand, nose downwards, and the bricks and loose basic material raised on a small hydraulic hoist inside the converter as required, thereby considerably reducing the labour of bricking. The bricking is carried out from the nose upwards, and behind each course of bricks about 3 inches of loose basic material is rammed, which makes a very secure and compact lining. The ground dolomite used for the bricks is mixed with $7\frac{1}{2}$ to 10 per cent. of tar before being moulded into form in the hydraulic press, at a pressure of two tons per square inch.

Converter Tuyere Blocks.—These blocks are formed in a mould under a 3 ton steam hammer, after which they are fired in stoves by applying the heat very gradually until a cherry-red colour is obtained. The firing takes about 70 hours, after which the stoves are allowed to cool slowly. The tuyere blocks are now secured to the bottom part of the converter. The bottom section is placed on a revolving table, and the tuyere block is put in the centre of it, the space around the block and between the casing being filled with basic material properly rammed by a pneumatic hammer as the table revolves slowly. When this is completed, the converter sections are replaced, the top part being first

secured to the trunnion ring by the aid of the 100-ton crane and afterwards the bottom part by the specially constructed truck with hydraulically operated top.

Drying the Lining.—A wood fire is lighted in the converter, and coal added afterwards. A gentle blast is applied until the coal is incandescent. The drying is continued for about 20 hours, after which the vessel is ready for the metal.

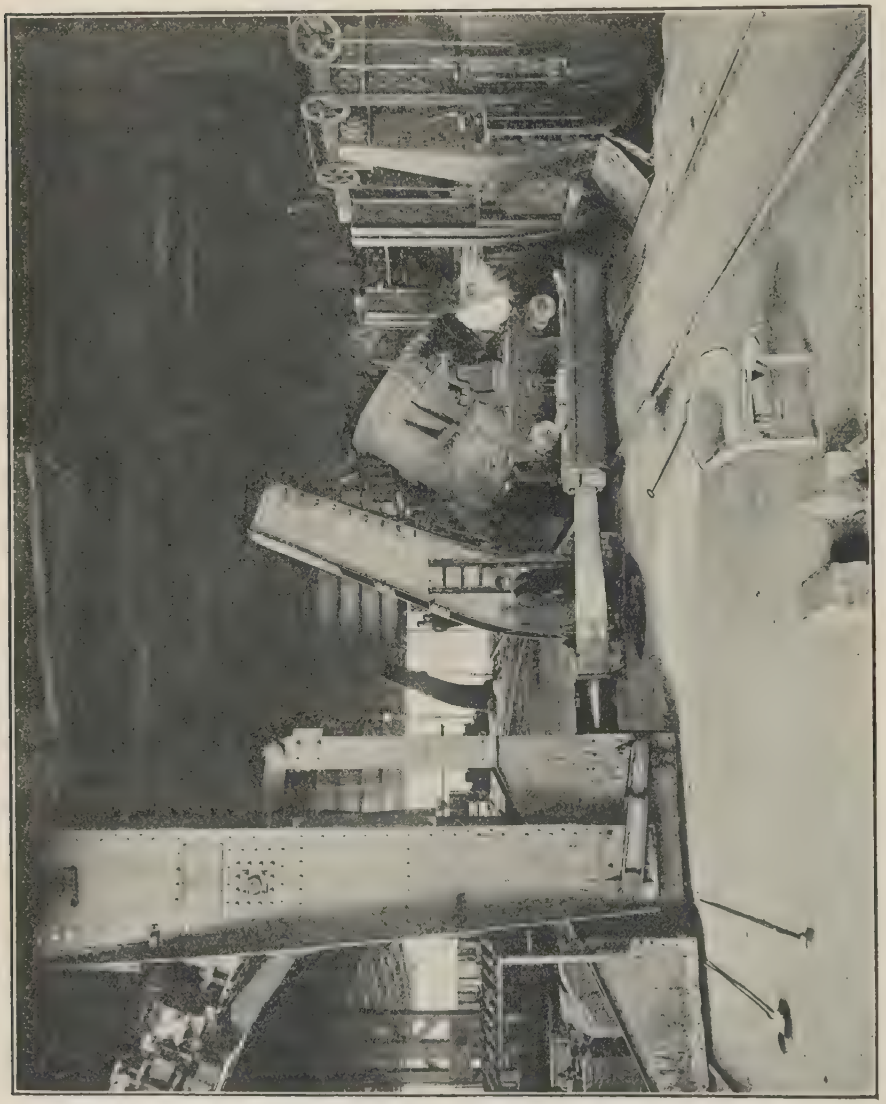


Fig. 80.—400-ton Mixer Platform. North-Eastern Steel Works, Middlesbrough.

Scrap and Lime Charging.—The method adopted for introducing the lime and scrap into the converters is well shown in Fig. 82, which is a photograph of the Bessemer stage. At the back of the converter staging there are two higher stages, one on which lime is stored, and from which it is charged into the

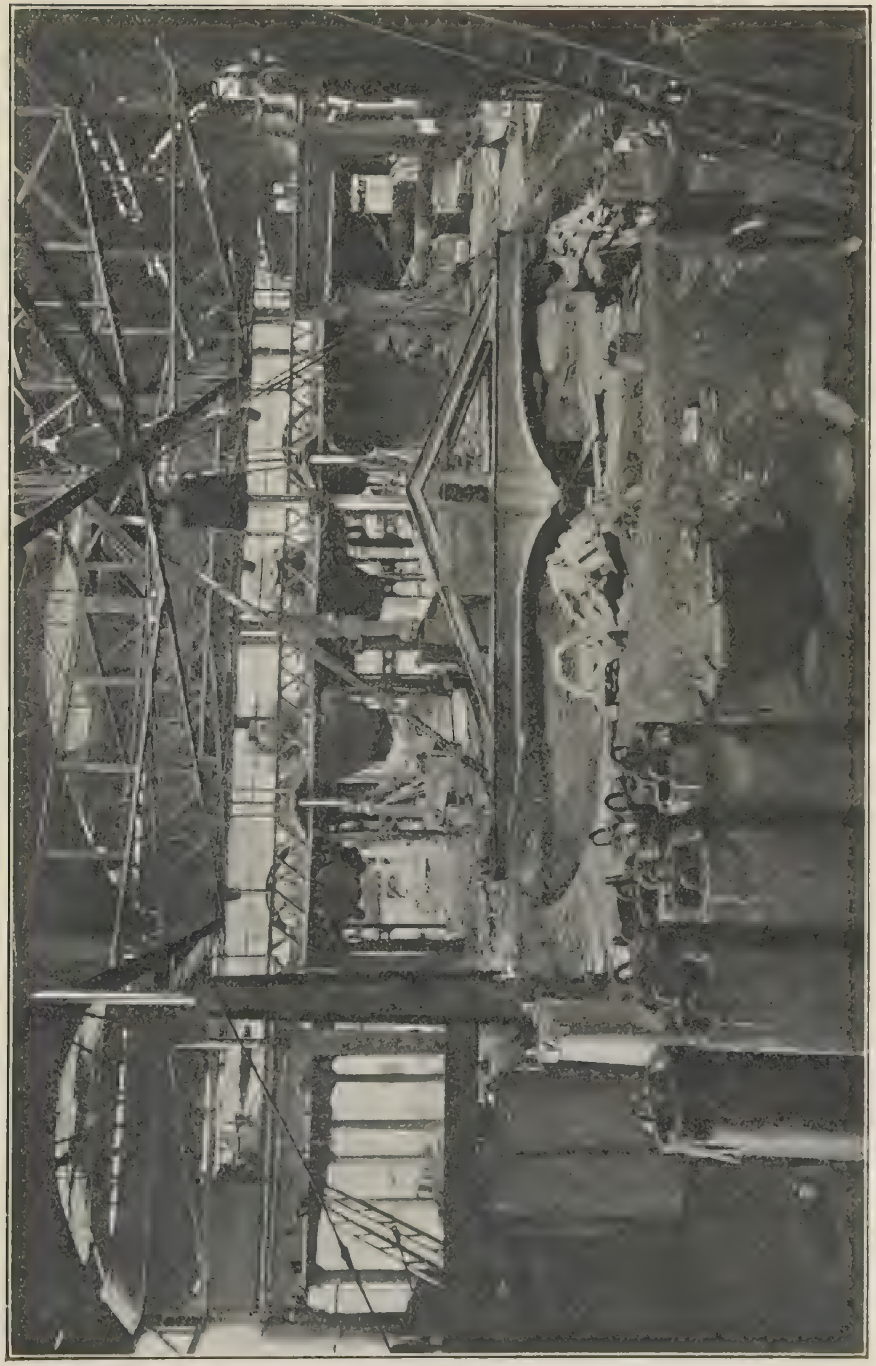


FIG. 81.—Bessemer Shop. North-Eastern Steel Works, Middlesbrough.

converter, the other and higher one being used for scrap steel. Arranged in line with each converter is a double chute projecting from the two platforms, down which the scrap and lime can be discharged into the converter before or during the blow. By this simple device, both time and labour are saved in charging these materials.

Arrangement of Cranes.—Each pair of converters is served with a 20-ton hydraulic crane, which supports the ladle at the end of its jib, into which the contents of the converter are poured. The ladle of steel is transferred to the casting crane direct to the ingot casting pit, around which are 5-ton hydraulic cranes for the removal of ingot moulds, ingots, etc. Fig. 81 shows a photograph of the Bessemer shop with the central casting pit crane.

American Bessemer Practice

The development of the Bessemer process in America was very rapid for several years, but the open-hearth furnace appears to have arrested its progress. In 1873 the total steel produced in the U.S.A. equalled 143,000 tons, 70 per cent. of which was Bessemer steel, and less than 3000 tons open-hearth steel. In 1880 the Bessemer steel output was 1,000,000 tons, and the open-hearth steel first exceeded 100,000 tons. In 1907 over 23,000,000 tons of steel were produced, in about equal amounts of Bessemer and open-hearth steel, and in 1911 the figures were as follows:—

Bessemer steel (acid),	7,947,849 tons	= 33·6%	of total output
Open-hearth steel (acid),	912,718 ,,	= 3·8%	,, ,,
,, ,, ,, (basic),	14,685,932 ,,	= 62·2%	,, ,,

Table LVI shows the production of acid and basic Bessemer steel ingots during the past 30 years, compared with the open-hearth steel produced during the same period. This illustrates the relative rate of production by each process, and shows how the open-hearth process has taken a firm hold in America.

TABLE LVI

Output of Acid and Basic Bessemer Steel Ingots[1] in the U.S.A. from 1880 to 1910 compared with Output of Acid and Basic Open-hearth Steel Ingots during the Same Period

	1880.	1890.	1900.	1910.
Acid Bessemer	1,074,268	3,611,091	6,684,770	9,412,772
Basic ,, ...	Not classified	77,780	—	—
Acid open-hearth . . .	100,851	423,232	853,044	1,212,180
Basic ,, ,, . . .	Not classified	90,000	2,545,091	15,292,329

In 1890,[2] the largest Bessemer converter in the U.S.A. had a capacity of 11½ tons, and in 1906, 18 tons. The rated capacities of the average converter in the two years named were 6·55 and 10·44 tons respectively, and the average output per ton of rated converter capacity was 7103 and 18,934 tons respectively. This vast difference was due to the accelerated rate of output per converter, owing to the introduction of the mixer and better machinery for handling the materials. For some years prior to 1906, no additional Bessemer plants had

[1] "Journal Iron and Steel Institute," 1912, I, pp. 48, 49.
[2] "Electrochemical and Metallurgical Industry," vol. v, p. 114.

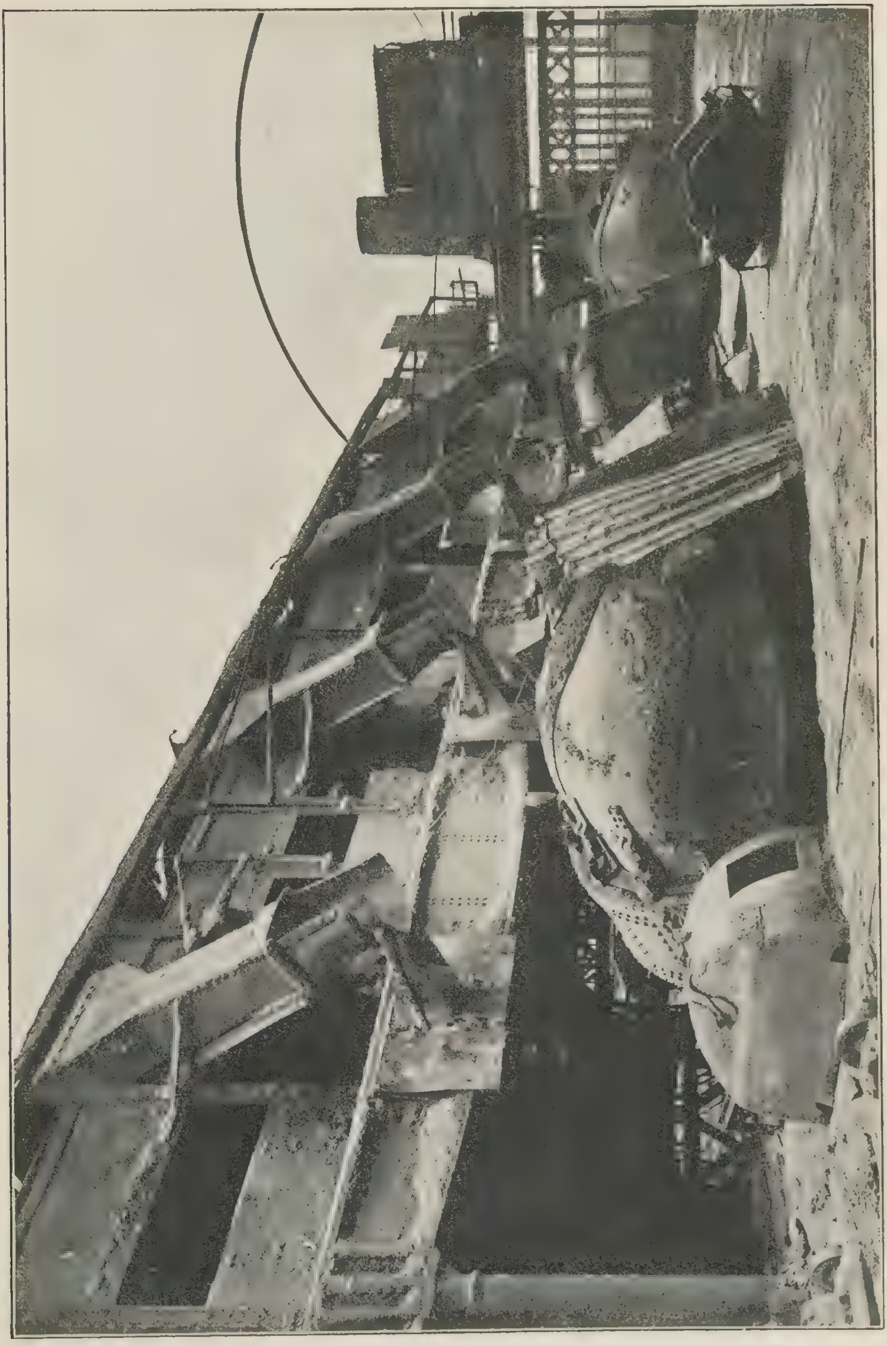


FIG. 82.—Bessemer Stage. North-Eastern Steel Works, Middlesbrough.

been installed in the States, while all along, open-hearth furnaces were being erected. In that year the Youngstown Steel and Tube Co.[1] built a new Bessemer plant, in which were embodied the best features of modern practice.

10-ton Converter Plant at Youngstown.—In Fig. 83 is given a plan of the

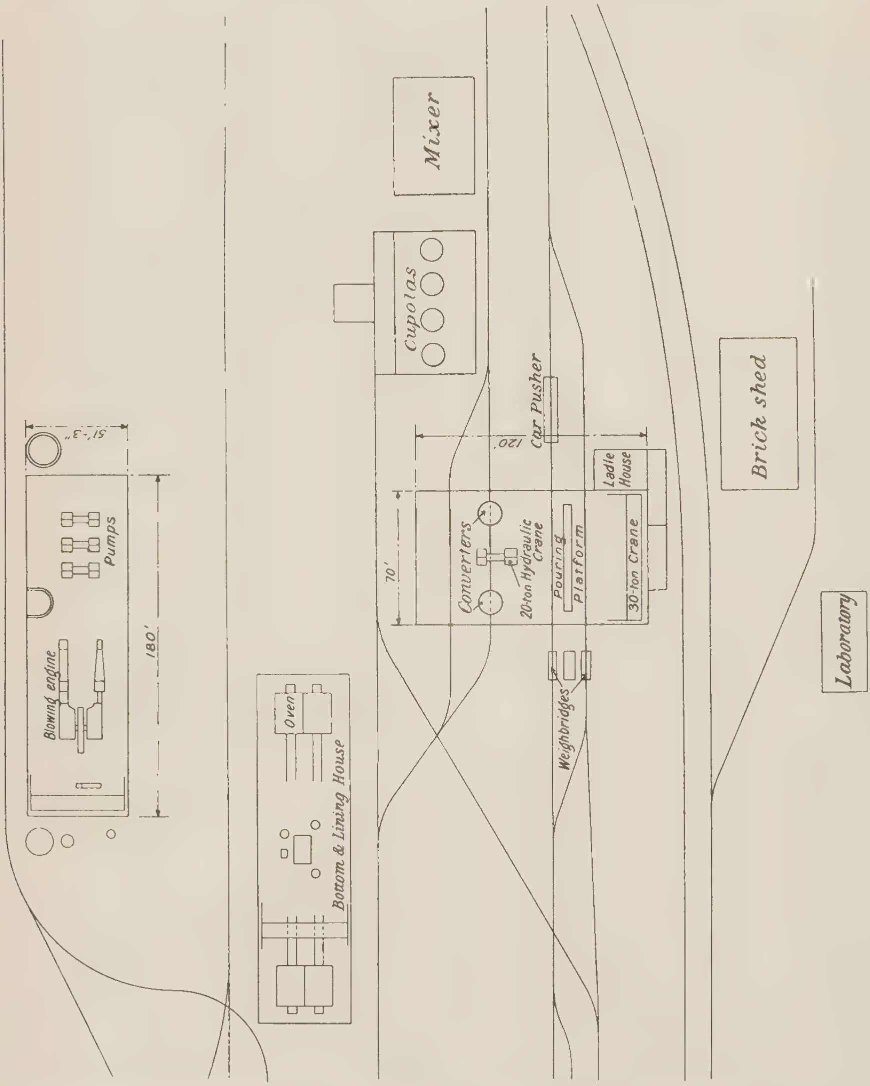


FIG. 83.—Plan of the Youngstown Sheet and Tube Co.'s Steel Works, Youngstown, U.S.A.

above works, on which are indicated the cupola and converter houses with the auxiliary plant and buildings.

Cupolas.—There are 4 cupolas in which the pig iron is melted for the converters. The charges are raised to the platform by means of two hoists, each of 10 tons capacity. Before the car loads of pig iron, fuel, and fluxes are raised,

[1] "Iron Age," Aug. 2nd, 1906, p. 260.

they pass over a weighbridge close to the elevators, and a check is kept on the materials used. Each pair of cupolas has a runner, along which the metal flows into a ladle on a truck which is taken to the converters. The slag from the cupolas is conveyed down chutes to the floor below into slag-pan cars, which are removed when full. On the tapping stage are erected the blowers for supplying air to the cupolas, each blower being separately driven by direct connection with an electric motor of 75 h.p. running at 1500 revolutions per minute.

Converters.—There are 2 converters, each of 10 tons capacity, and arranged as shown in Fig. 83. They are mounted in pedestals fixed to foundations level with the casting floor, and instead of being erected in one line, the converters face each other with a 20-ton hydraulic crane between them, which serves both. An overhead electric crane of 30 tons capacity is also available for use.

The molten metal from the cupolas is taken to the converters, and before the metal is poured into the converter by means of an electrical tipping device, it is weighed on a weighbridge on the platform in front of the converter. The charge, when ready, is emptied into a ladle supported by a 20-ton hydraulic crane, and transferred to the casting crane.

Bottom and Lining House.—A commodious house, 50′ × 120′, is used for preparing the refractory materials for making the bottoms and lining materials. The shop is equipped with one crusher, two wet grinding pans, and one dry one. The converter bottoms are dried in ovens which are built in a lean-to at each end of the building.

German Bessemer Practice

Germany leads the world in Basic Bessemer steel manufacture, its production is on the increase, and far exceeds the open-hearth furnace production, as shown by the following statistics:—In 1860, a total of 25,312 metric tons of steel were produced, whereas in 1911, 14,879,919 tons were made, out of which 8,640,164 tons were from Basic Bessemer converters. In Table LVII is shown the production of acid and basic Bessemer steel ingots for the past 30 years, compared with the open-hearth steel produced during the same period.

TABLE LVII

Output of Acid and Basic Bessemer Steel Ingots[1] in Germany from 1880 to 1910 compared with Output of Acid and Basic Open-hearth Steel Ingots during the Same Period

	1880.	1890.	1900.	1910.
Acid Bessemer	742,000	—	223,063	171,108
Basic ,, ...	18,000	1,493,157	4,141,587	8,030,571
Acid Open-hearth . . .	—	—	147,800	140,189
Basic ,, ,, . . .	—	—	1,997,765	4,973,569

Bessemer plants in Germany differ in construction from each other as in other countries, but the spirit of progress is fully developed, and constant improvements are being introduced in different parts of the auxiliary plant, to facilitate economical output. The plant installed a few years ago at the Burbach Works, in the Saar district, is typical of the best progress in German Basic Bessemer plants.

[1] "Journal Iron and Steel Institute," 1912, I, pp. 48, 49.

24-ton Converter Plant at Burbach.

General Description.—In Fig. 84 and in Plates I and II are illustrated the 24-ton Basic Bessemer plant[1] designed by E. Widekind of Düsseldorf, and

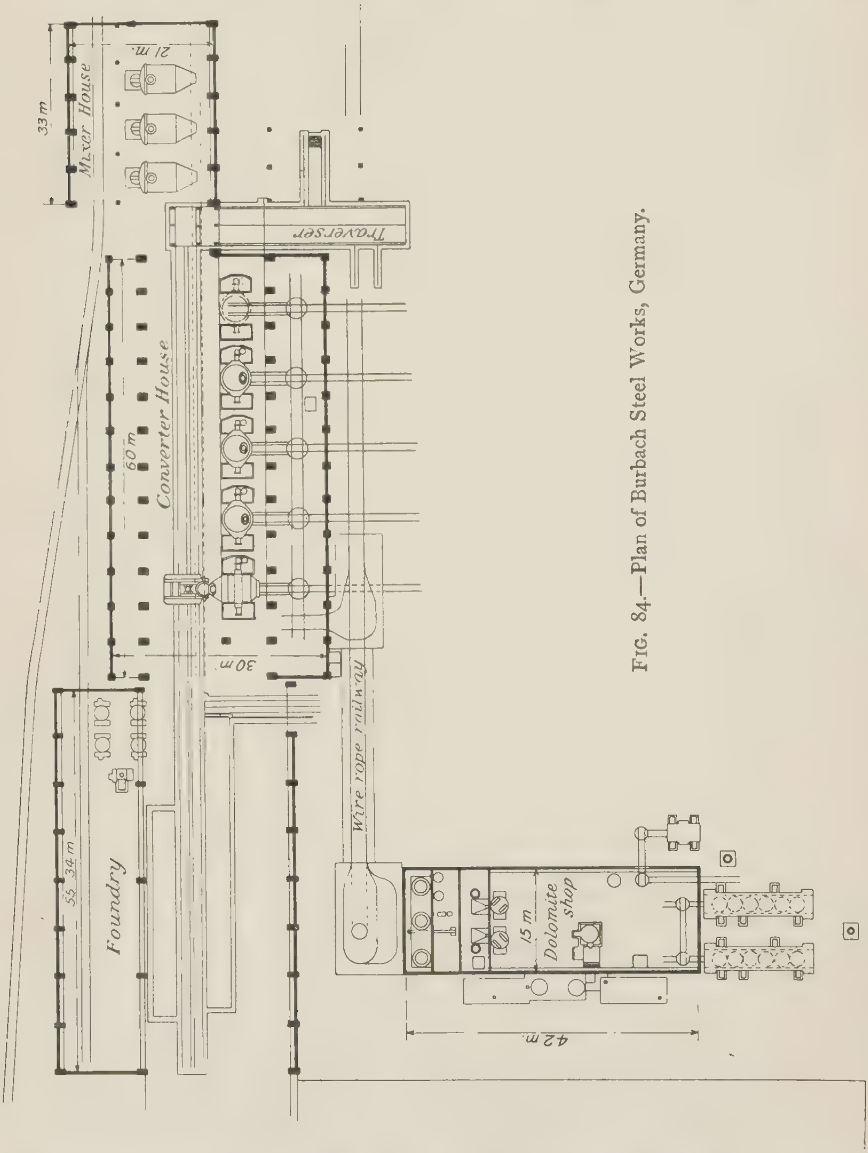


FIG. 84.—Plan of Burbach Steel Works, Germany.

installed in the Burbach Works, in 1908. There are several special features about the construction of the converters and auxiliary plant which favour rapid production of steel.

[1] By the kind permission of the Designer, and the Editors of "Stahl und Eisen."

The metal is taken direct from the blast-furnaces in ladles of 18-tons capacity, of the steam locomotive type, to the mixers, of which there are three, each of 210 tons capacity. Two are kept in constant operation, being charged and emptied alternately. Outside the mixer-house the ladle of metal is weighed on a weighbridge, after which it is transferred from its carriage by an overhead electric crane of 35 tons capacity to the mixer, into which the contents of the ladle are poured by an auxiliary tipper on the same crane. Slags from the mixer are poured into a box conveniently placed on pedestals below, and within crane range, so that when full it can be lifted and placed for removal on a truck on the floor-level. The space under the mixer staging is used for the storage of materials, and also for the various washing and bathing conveniences for the men and staff. From the mixer, the metal is taken to the converters in electrically driven trucks, having ladles of 24 tons capacity. The ladles are also

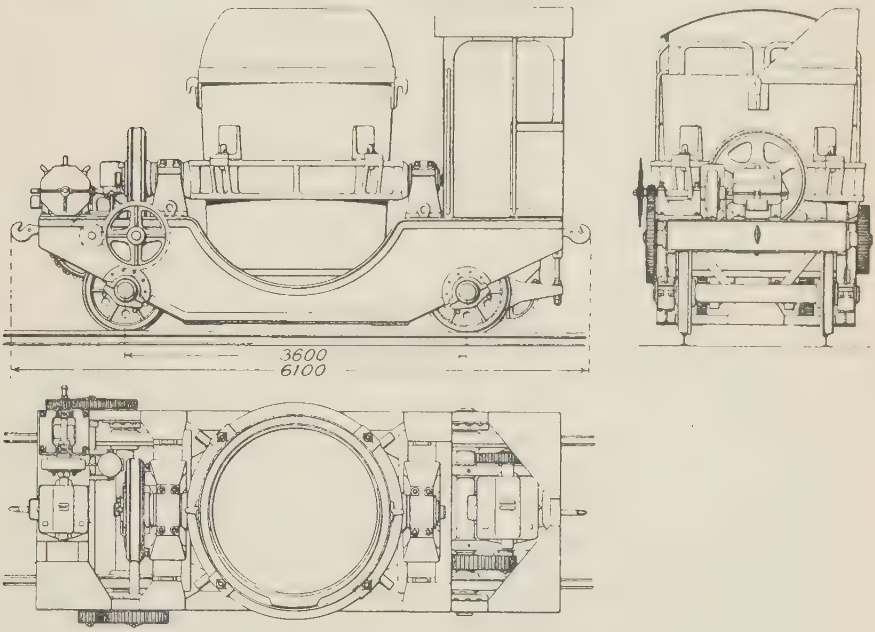


FIG. 85.—Electrically operated Ladle Truck.
(Dimensions in millimetres.)

electrically tipped, and all the gearing and motors on the truck and about the ladle are enclosed. Fig. 85 shows views of the ladle-truck. Before the metal is poured into the converter it is weighed on a weighbridge.

Converters.—The body of each converter is of ordinary construction, with an eccentric nose. The lubricating arrangement of the trunnions is of special design and provides for a liberal allowance of lubricant when the converter is being tilted, but is shut off when it is at rest. The arrangement is shown in Fig. 86. The oil press is operated from the trunnion by a chain drive, which gives motion to the press, forcing the oil into the trunnion bearings at a pressure of 750 lbs. to the square inch. In addition to this special lubricating appliance, a large cavity in the cap of the trunnion contains a liberal supply of solid grease to provide against any possible failure of the other supply.

Each converter is tilted in the ordinary way by means of a rack and pinion

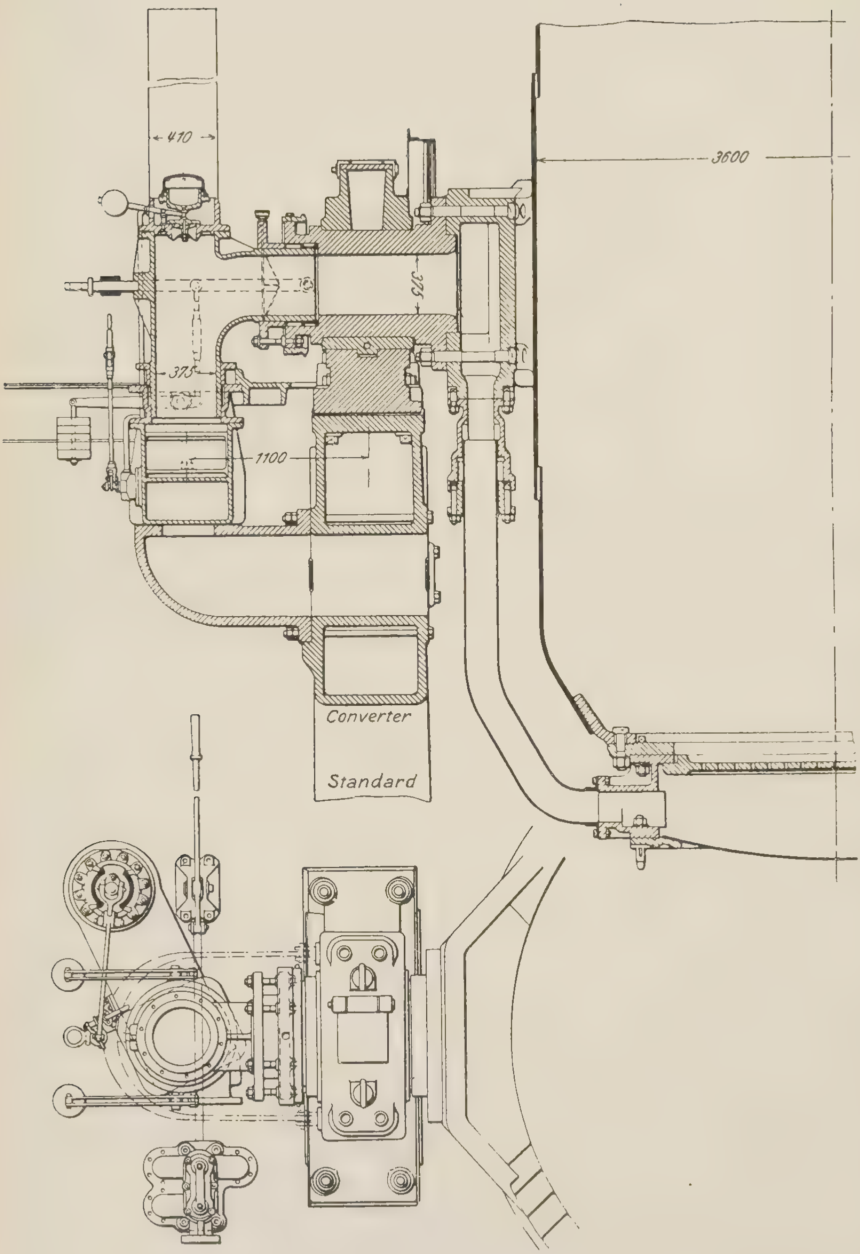


FIG. 86.—Detail of Trunnion Bearing and Operating Valves for 24-ton Converter. (Dimensions in millimetres.)

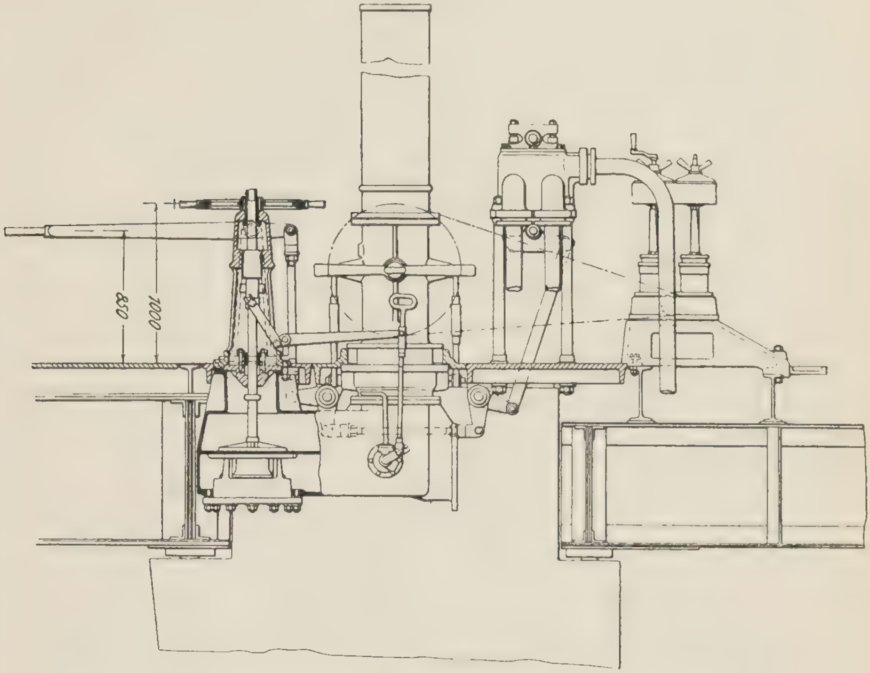


FIG. 86.

operated by a hydraulic cylinder. The rack is kept in gear with the pinion by means of a guide faced with gunmetal. The hydraulic cylinder is 26 inches diameter and has a stroke of 134 inches, giving the vessel movement through 282 degrees. All the gearing is well protected. The converter is operated by means of valves for admitting the blast and tilting the converter. Signalling apparatus to the engine house is also under the command of the operator. The valves are mounted on the opposite side of the converter to the tipping cylinder and gear, and in such a position that the man in charge can see the converter in every position.

The air is admitted to the double-seated valve chest shown in Fig. 86, from the blast engine mains, and passes through the trunnion to the wind chest at the bottom of the converter. A safety-valve is fixed on a T-piece from the trunnion, and is operated automatically from the blast valve; it can be operated also by hand. A non-return valve is fixed on the blast main in front of the blast valve, and closes automatically when the latter is shut. Pressure gauges record the pressure on both sides of the main valve.

The blast is supplied to the converter plant by 3 steam-driven blast engines, having the following capacities: 32,000 cubic feet of air per minute at $37\frac{1}{2}$ lbs. pressure per square inch; 32,000 cubic feet at 30 lbs. per square inch; and 21,000 cubic feet at 30 lbs. per square inch.

Cupolas for Spiegeleisen.—Two cupolas for melting spiegeleisen are erected close to the converter plant, and each is capable of melting $1\frac{1}{2}$ tons in 20 minutes, or 4 to 5 tons per hour. The metal from them is tapped into ladles mounted on trucks and conveyed to the converters, into which their contents are tipped by hand gear. The cupolas are supplied with blast from a direct

coupled motor-driven blower, delivering 3250 cubic feet of air per minute. A non-return valve is fitted on the main pipe. Fig. 87 shows sections of the cupolas, and details of the bricks used for lining.

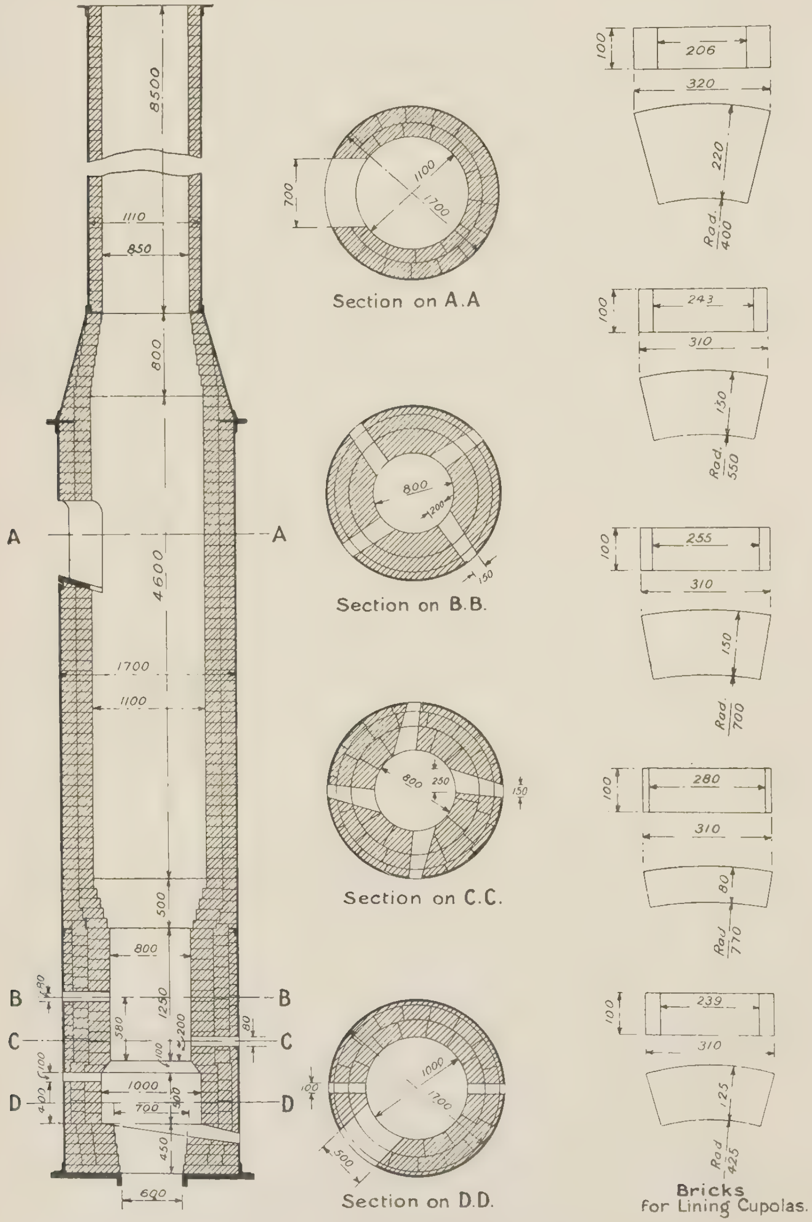


FIG. 87.—Spiegel Melting Cupola.

On the lime charging stage a furnace is provided for heating ferro-manganese, which is conveyed red-hot to the converters by means of swing pipes.

The dolomite and lime used in the converters are supplied from overhead storage hoppers, and conveyed in trucks from them to the feed hoppers over the converters.

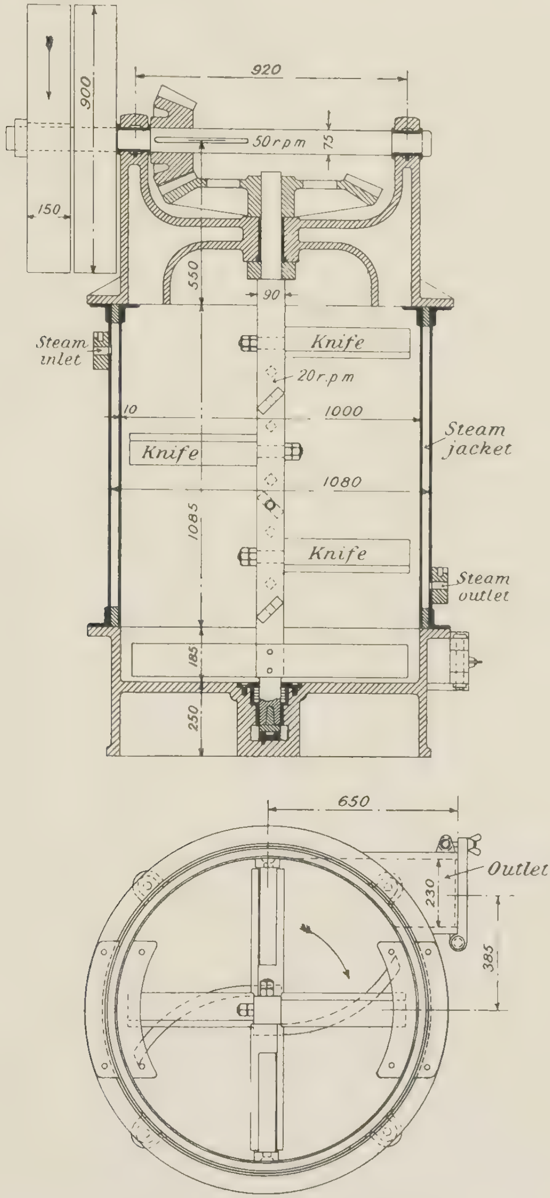


FIG. 88.—Dolomite and Tar Mixer.

Scrap, ferro-manganese, and spiegel are elevated to their respective platforms by means of a $1\frac{1}{2}$-ton electric hoist, operated by a $12\frac{1}{2}$-h.p. motor.

Bricks for lining the converters are raised by an electric travelling winch.

Lining of Converters.—The converters are lined with dolomite bricks made in the dolomite plant. Fig. 76 (p. 148) shows how the courses of brickwork are arranged in the converters, and the sizes of the bricks used are also given. The bricks are made in a hydraulic press from finely ground and prepared dolomite, of the consistency found most suitable for the walls of the converter. The moulds in which the bricks are formed must be of ample dimensions, as the pressure per

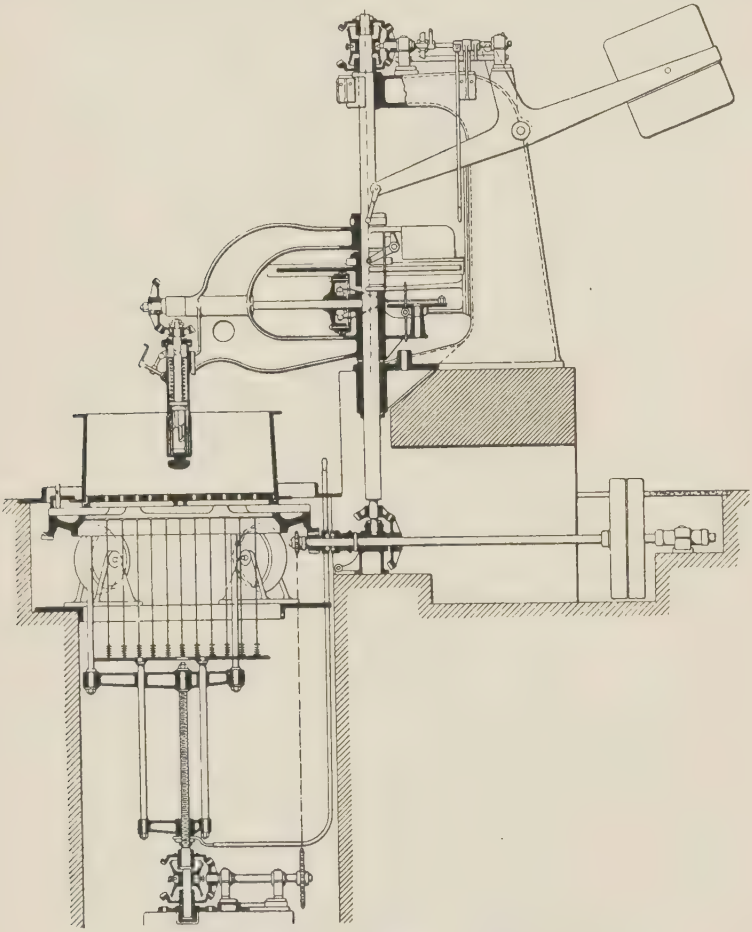


FIG. 89.—Machine for making Converter Bottoms.

square inch to which the dolomite is subjected is 4500 lbs. The bricks are ejected from the moulds by a supplementary ram, which exerts a pressure of 750 lbs. per square inch. The bricks are dried in suitable kilns before use.

The dolomite and tar mixture used in the converter lining is made in a machine with a cylindrical steam-jacketed casing, in which is driven a revolving shaft carrying knives which pass between fixed knives in the cylinder. The material is fed in at the top and discharged at the bottom of the cylinder into trucks. Fig. 88 shows two views of the machine.

Converter Bottoms.—The bottoms are stamped in a press of special construction, shown in Fig. 89. The casing in which the dolomite is rammed

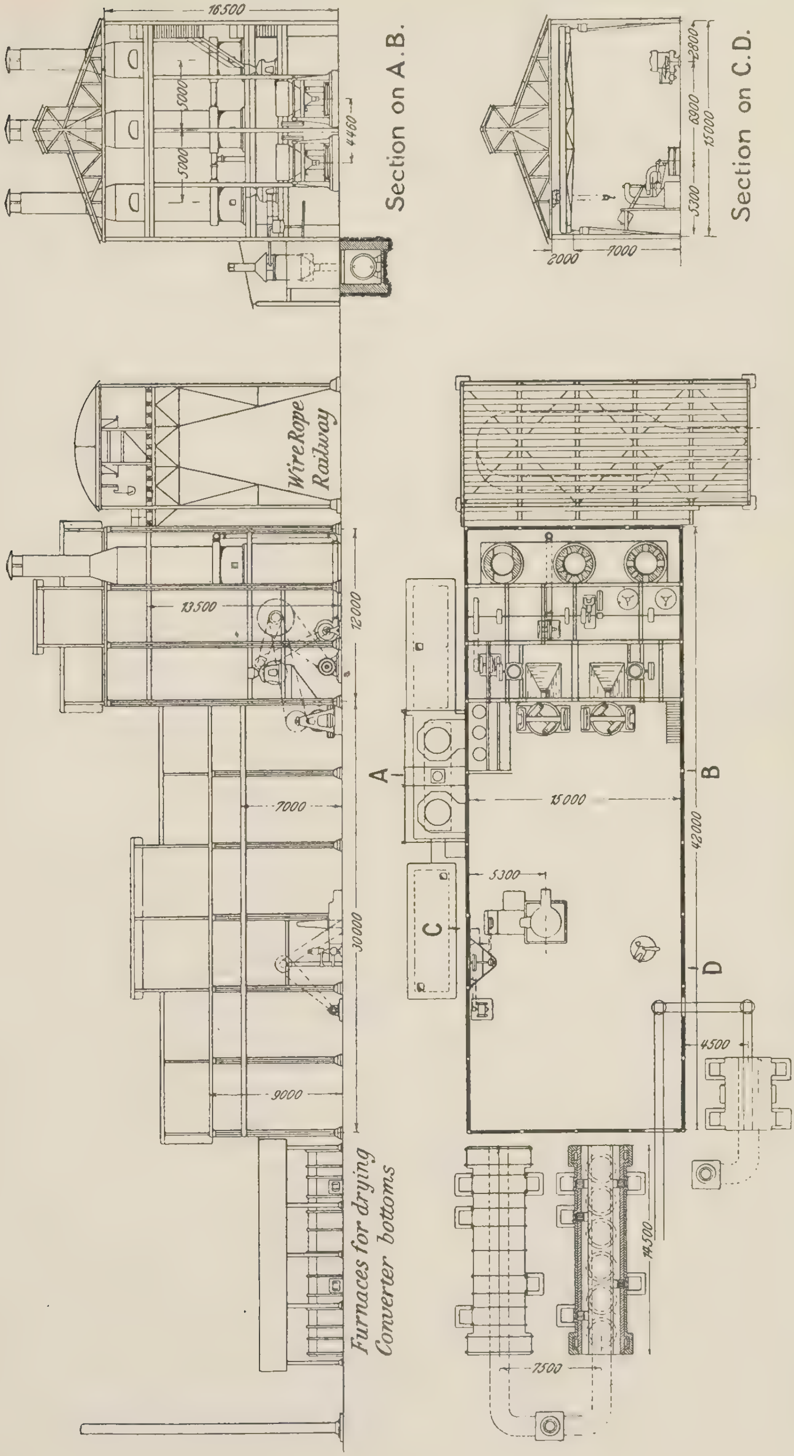


Fig. 90.—Arrangement of Dolomite Plant, Burbach Steel Works.

is placed on the table of the machine which rotates, while the rammer, mounted on a swinging arm over the casing, makes rapid strokes upon the mass of dolomite scattered over the bottom. To maintain uniformity of pressure and

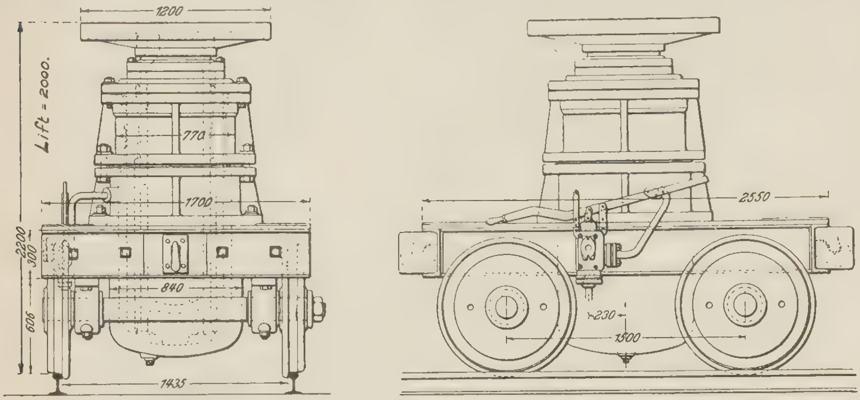


FIG. 91.—Hydraulic Truck for removing and replacing Converter Bottoms.

equal distribution of strokes over the surface of the bottom, the movement of the rammer and the number of strokes per revolution of the table are automatically regulated. The air holes through the bottom are made by 250 needles, $\frac{5}{8}$ inch diameter, which are caused to pierce the dolomite gradually during the operation of ramming, care being taken to keep them just below the surface of the dolomite during the operation, to prevent damage to the needles. When the bottom is completed it is withdrawn. The time taken by this machine to mould a bottom is from 2 to $2\frac{1}{2}$ hours. It is operated by a motor of 10 to 12-h.p.

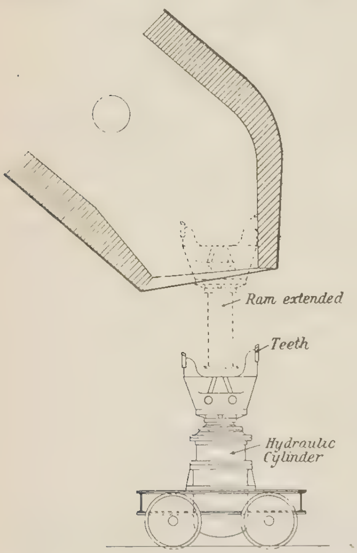


FIG. 92.—Method of Dislodging Incrustation from Converter lining.

The firing of the bottoms is carried out in specially designed kilns, in each of which 6 bottoms can be fired at one time. The arrangement of placing in and removing the bottoms from the furnace is very simple and effective. The bottoms are carried to the furnace on railway trucks fitted with a hydraulic ram for raising and lowering the bottoms as required. The bottom is run into the furnace and is lowered upon two side supports, a plate being under it to carry the weight. The truck is then removed from the furnace until after the firing is done, when it is used for the removal of the bottom from the furnace. Fig. 90 shows arrangement of dolomite plant.

Fixing Converter Bottoms.—A special truck with hydraulic ram, shown in Fig. 91, is used for conveying the bottoms to the converters and raising them in position, after which they are fixed to the converter body. The rams are $17\frac{3}{4}$ inches and $24\frac{1}{2}$ inches diameter, with a total lift of $6\frac{1}{2}$ feet. The rams are

operated by power supplied through a flexible hose-pipe connected with the hydraulic mains.

This same truck is used for dislodging incrustation which gathers round the mouth of the converter. On the smaller ram is fixed a head fitted with scrapers, or teeth, which operate on the lining as shown in Fig. 92. This is done after the converter has been emptied and while it is still hot.

The removal of the wind chest cover is effected by levers suspended from the overhead traveller, fitted with stirrups engaging with the hooks on the cover. The burnt-out lining in the bottom is knocked out by means of a ram suspended from overhead, the outer ring being chipped out with pneumatic hammers.

CHAPTER XVI

BLOWING ENGINES FOR BESSEMER CONVERTERS

Blowing Engines for supplying blast to Bessemer converters are of more numerous types than they were a few years ago. For a considerable period, the usual method of producing the necessary blast for the blow was by a double-cylinder horizontal or vertical steam-blowing engine, and even to this day this still predominates. In addition to the reciprocating steam-blowing engine there are available :—Gas-driven blowing engines, motor-driven blowing engines, and turbo blowers, and the selection of one or other of these is a matter for some consideration. With the older plants, the steam for the steam-driven blowing engine was, and still is, usually obtained from a steam-boiler plant, the steam being generated from coal fuel in the ordinary way. Of recent years, however, the economy of utilising the waste heat from reheating furnaces in the works, by means of water-tube boilers, has led in some cases to an alteration in the steam generating plant, whilst still retaining the blowing engine in its old form. Again, in works where blast furnaces are installed, the utilisation of the blast furnace gas has been of economy at the converter plant, where, although the steam-driven blowing engine may still be retained, the steam is generated in boilers fired by the blast furnace gas.

In modern works where an entirely new plant has to be installed, or in older works where it has been seen that a distinct economy could be obtained by discarding their existing steam-driven plant, the blowing engine driven by blast furnace gas has made considerable progress. With the advent also of satisfactory electrical plants and the cheap cost of power, the motor-driven converter blower is finding favour in works possessing a large electrical generating plant, or where current can be purchased cheaply from a supply company or corporation.

The comparative costs given in the following summaries, are for blowing engines of about 4000 h.p. suitable for a converter plant producing say 400,000 tons of ingots per annum, and are abstracted from a paper read before the International Congress at Düsseldorf, in 1910, by Mr. Mauritz. In each case, the rate of depreciation and interest combined has been taken at 6 per cent. for buildings and 12 per cent. for plant and foundations. The figures are typical only, and require verification in each individual case to insure that the costs given of fuel, gas, water, electricity, etc., are in keeping with the particular district in which the plant is situated or to be installed.

Steam-driven Blowing Engines (Coal-fired Boilers).—The capital expenditure for a complete steam-driven blowing engine of about 4000 h.p. with condenser, coal-fired boilers, superheaters and economiser, pipes, chimney, buildings with crane, and foundations, is approximately £22,800. The consumption of water for the above plant, on the basis of a steam consumption of 550 lbs. per ton of ingots produced, is about 1600 gallons per ton. Assuming

that a plentiful water supply is available, and charging for water at the rate of ·55*d.* per 1000 gallons (assuming also that the water is not used over again), the following annual running costs are obtained :—

Cost of plant £22,800.

	£
Depreciation and Interest	2525
Water supply	1450
Wages, stores, and repairs (@ 1·668*d.* per ton of ingots) .	2775
Coal (7·5 evaporative power, on the basis of 550 lbs. of steam per ton of ingots) @ 10*s.* per ton	6690
Annual cost . .	£13,440

With an annual production of 400,000 tons of steel, the cost of power per ton of steel $= \frac{13{,}440 \times 20}{400{,}000} = 8{\cdot}06d.$

In the case of a plant utilising the waste heat from reheating furnaces for raising the steam in water-tube boilers, these figures would of necessity have to be modified to suit the particular conditions of working.

Steam-driven Blowing Engines (Gas-fired Boilers).—With plants operating with gas-fired boilers, the following may be taken as typical figures. The capital expenditure for a complete steam-driven blowing engine of about 4000 h.p. without economiser, and assuming that the boilers were in the open air, would be approximately £26,300. Blast furnace gas is assumed to be charged to the boilers at the rate of 1*d.* per 3270 cubic feet of gas of 101 B.Th.U.'s per cubic foot heat value, corresponding to coal at 10*s.* per ton. Annual running costs :—

Cost of plant £26,300.

	£
Depreciation and interest	3000
Water supply	1450
Wages, stores, and repairs (@ 1·056*d.* per ton of ingots) .	1690
Blast furnace gas @ 1*d.* per 3270 cubic feet	6650
Annual cost . .	£12,790

With an annual production of 400,000 tons of steel, the cost of power per ton of steel $= \frac{12{,}790 \times 20}{400{,}000} = 7{\cdot}68d.$

An illustration of a typical steam-driven cross-compound steeple type converter blowing engine, manufactured by Messrs. Galloways, Ltd., Manchester, is shown in Plate III, Fig. 93. This engine is made for a working pressure of 125 lbs. per square inch in the high-pressure steam cylinder, and runs at 50 r.p.m. delivering 35,000 cubic feet of air per minute at a pressure of 20 lbs. per square inch.

In Fig. 94 is shown a photograph[1] of a large blowing engine recently installed at the Steel Works of Senelle-Maubeuge, France. The engine is of the cross-compound horizontal type, the leading particulars being :—

[1] Kindly supplied by the makers, Messrs. Leflaive & Co., St. Etienne.

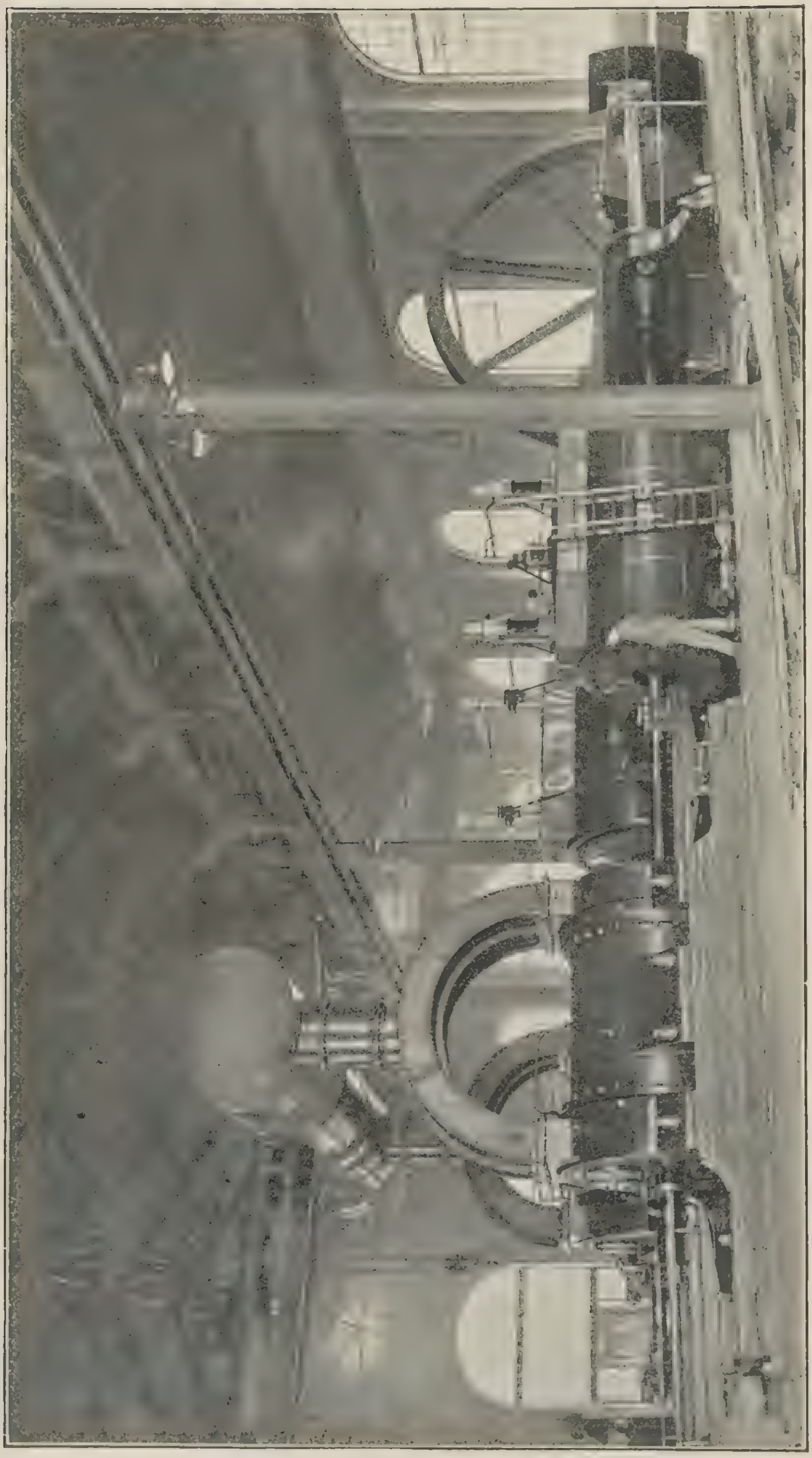


Fig. 94.—Steam-driven Blowing Engine. Leflaive's Cross-compound Horizontal Type.

Diam. of high pressure steam cylinder	1·30 m. (51·2 in.).
,, low ,, ,,	2·00 m. (78·75 in.).
,, each air cylinder	1·80 m. (70·9 in.).
Length of stroke	1·70 m. (66·9 in.).
Revolutions per minute	60
Steam pressure	120 lbs. per sq. inch.
Air ,,	35·5 ,, ,,
Maximum volume of air per minute	1000 cu. metres (35,300 c. ft.).
Normal horse-power	4000
Total weight	350 tons.

This blowing engine is used in conjunction with 18–20 ton converters, the average duration of the blow being 10 minutes.

Gas Blowing Engines.—An illustration of a gas blowing engine made by the M.A.N. Co., Augsburg, Germany, is shown in Fig. 95. An engine of this description, suitable for 25-ton Bessemer converters, will cost, completely erected but without foundations and piping, about £20,000. These engines are simple in operation, the quantity of air delivered and the air pressure being governed by a hand regulator. A governor switches off the ignition when the permissible speed is exceeded, and switches it on again when the engine resumes its normal speed. At the end of the blow, if there is not another converter ready for blowing, the engine is not stopped, but the air supply is cut off from the converters by means of a balanced valve, which is placed in the blast piping and worked by a relay. The air thus escapes into the atmosphere, and the engine runs at no-load until the valve is closed and the blowing operation is started again. During the pause between the blows the engine runs at a slow speed, and the gas consumption is therefore small.

In the gas blowing engines made by Thyssen and Co., Ltd., Mülheim-Ruhr, Germany, the speed regulation of the engine is effected by the lift of the mixture valve, by which it is possible to vary the number of revolutions from 20 to 95 per minute. The air supply is controlled by a rotary valve in the blast cylinder cover, which in different positions either connects the cylinder chamber with the outer air or with an additional closed space, or when working with full-load shuts off both connections.

The capital expenditure for a complete gas blowing engine of about 4000 h.p. for working on blast furnace gas, with compressed air starting apparatus, circulating water pump, pipes, buildings with crane, and foundations is approximately £27,000. This cost does not include gas-purifying plant. The consumption of blast furnace gas (101 B.Th.U.'s per cu. ft.) per ton of ingots produced is taken at 4940 cubic feet, and it is assumed that it is charged to the steel plant at the rate of 1*d.* per 3270 cubic feet, *i.e.* corresponding to coal at 10*s.* per ton. Annual running costs:—

Cost of plant £27,000.

	£
Depreciation and interest	3050
Water supply	485
Wages, stores, and repairs (@ 1·056*d.* per ton of ingots)	1690
Blast furnace gas @ 1*d.* per 3270 cubic feet	2600
Annual cost	£7825

With an annual production of 400,000 tons of steel, the cost of power per ton of steel $= \frac{7825 \times 20}{400,000} = 4{\cdot}7d.$

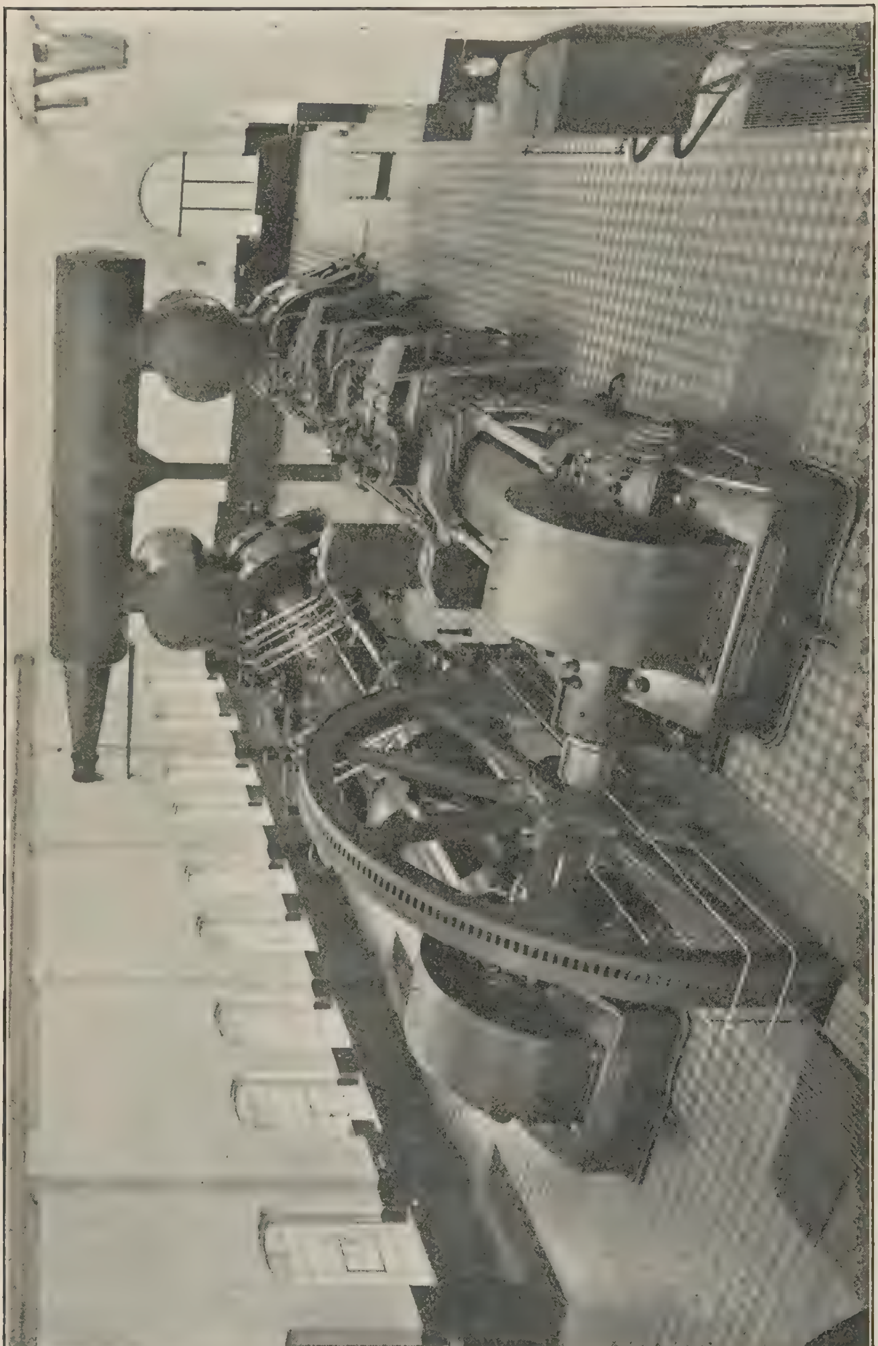


FIG. 95.—Gas Blowing Engine, M. A. N. Type.

Motor-driven Blowing Engines.—An illustration[1] of a 2000 h.p. direct current converter blower made by the Felten and Guilleaume-Lahmeyerwerke A. G., Frankfort, Germany, and installed at the A. G. Peiner Walzwerk, Peine, Hanover, is shown in Plate IV, Fig. 96. The motor can be varied in speed from 22 revs. (at which speed it gives out 600 h.p.) to 80 revs. per minute. The electrical supply is taken to the works from a power station at Ilsede, 4 miles away, at a pressure of 10,000 volts A.C. It is converted at the Peine works to 500 volts D.C. From records taken of the consumption of electricity, it has been found that 30 k.w. hours are consumed per ton of ingots produced. This figure includes the loss in transmission and conversion from A.C. to D.C., and it is probable that the consumption of electricity where no transmission was necessary, would be about 25 k.w. hours per ton. At these works the average duration of the "blow" is about 13 minutes, and the pause between the "blows" from 18 to 24 minutes. During the pause, the motor is kept running light. The power consumption (at $\frac{3}{8}$*d.* per unit) costs 8*s.* 6*d.* per "blow," and 1*s.* 4*d.* per pause. The size of the converters is 15 tons.

The capital expenditure for a complete motor-driven reciprocating blowing engine of about 4000 h.p., including continuous current motors, cables, switchboard, electrical conductors in the power house, overhead crane, buildings, and foundations, is approximately £17,100. Annual running costs :—

Cost of Plant, £17,100

	£
Depreciation and interest	1900
Water supply	25
Wages, stores, and repairs (@ ·18*d.* per ton of ingots) . .	300
Electricity (25 k.w. hours per ton of ingots) @ ·18*d.* per k.w. hour	7500
Annual cost .	£9725

With an annual production of 400,000 tons of steel, the cost of power per ton of steel $= \frac{9725 \times 20}{400,000} = 5{\cdot}83d.$

Turbo Blowers.—Turbo blowers are coming into use in this branch of steel manufacture, and they have advantages over the reciprocating blowing engines in that they take up less room and require less expensive foundations. They are not, however, fully developed for use with converter plants, but it is probable that in the future they will prove to be as economical as the other types of blowing engines for Bessemer plants.

[1] "Stahl und Eisen," vol. 29, July 14th, 1909.

CHAPTER XVII

COST OF STEEL PRODUCED IN LARGE BESSEMER CONVERTERS FOR INGOTS

In considering the cost of steel produced in large converter plants, the value of the liquid steel in the ladle is taken as the basis of calculation, and not the cost of ingots. It is not possible to give more than approximate costs for both acid and basic steel, which would be representative of the general practice at home and in other countries. It is therefore intended to give a general indication of each item of cost as would be found in modern works with the use of appliances where a minimum of handling by ordinary labour is required, and where plants are worked to their maximum capacity. In the first place, a plant with four 10-ton converters will be considered, and in the second, one with four 24-ton converters.

Cost of producing Steel in 10-ton Basic Bessemer Plant with Four Converters

Capacity of Plant.—With four 10-ton converters in regular commission, it is only advisable to count on 3 being in use at the same time, one of the four being always under repair. In each of the 3 converters, the duration of the blow varies from 10 to 25 minutes (as many as 50 minutes have been taken), or say an average of $17\frac{1}{2}$ minutes, but to this there must be added the time taken in charging the lime and for pouring the metal into, and the blown metal from, the converter, which may vary from 10 to 15 minutes.

Wedding[1] estimates that 40 minutes may be taken for an average heat, but even with this allowance a converter could not be constantly worked at this rate owing to the time occupied in changing bottoms. Twenty-four heats per converter per 24 hours is found to be a good working output. Larger outputs are obtained, but the cost of production will be based on 24 heats per 24 hours, or at the rate of 1 heat per vessel per hour. The weekly output, therefore, with $10\frac{1}{2}$, 12-hour shifts per week

$$= 10\tfrac{1}{2} \times 12 \times 3 \times 10 = 3780 \text{ tons.}$$

Working 48 weeks per year, the annual output

$$= 3780 \times 48 = 181{,}440 \text{ tons.}$$

Cost of Plant.—The cost of plant to produce the above output of steel would vary considerably according to the conditions of site and auxiliary plant used, but with all the most modern appliances and facilities for reducing labour to a

[1] Wedding, "Basic Process," p. 118.

minimum, the total cost would be approximately £90,000. This figure includes the following :—

1. Two mixers, each of 350 tons capacity, for use as collectors and desulphurisers only.

2. Two steam loco trucks, with ladles of 15 tons capacity.

3. One overhead electric crane in mixer house, of 30 tons lifting capacity, with 10-ton auxiliary crab.

4. Four 10-ton converters mounted on pedestals, with hydraulic tipping gear.

5. Two blowing engines to supply sufficient blast to blow two vessels at the one time.

6. Two 20-ton hydraulic or electrically operated cranes for serving the converters.

7. One 25-ton overhead electric casting crane.

8. One 80-ton overhead electric crane for handling the converters and serving in other directions.

9. Two special trucks, with hydraulically operated table rams for removing converter bottoms.

10. Two cupolas for spiegeleisen.

11. Two low-pressure blowers for cupolas.

12. One furnace for heating lime and ferro-manganese.

13. One hoist to cupola and furnace staging.

14. One hoist to converter staging.

15. All piping and valves for cupolas and converters.

16. All stagings, structural steelwork, chimneys, etc.

17. Two sets of hydraulic pumps, and accumulator.

18. Converter and mixer building.

19. Two weighbridges.

20. Steam boilers, 3000 h.p.

21. Dolomite house with plant.

22. Foundations for buildings and plant.

Blast furnaces are not included, the cost of the iron being taken delivered at the mixers.

Depreciation and Interest on Plant.—All parts of a Bessemer plant, including the auxiliary machinery, do not depreciate at the same rate. Some Bessemer plants are now at work which were installed over 30 years ago, but others have been reconstructed, or enlarged and modernised. Allowing a depreciation of 10 per cent. on the plant, 5 per cent. on the buildings, and $2\frac{1}{2}$ per cent. on the foundations, we have the following :—

	£
Depreciation on plant, 10 % of £60,000	6,000
„ „ buildings, 5 % of £20,000	1,000
„ „ foundations, $2\frac{1}{2}$ % of £10,000 . . .	250
Interest on capital, 5 % of £90,000	4,500
Total annual charge for depreciation and interest =	£11,750

Charge for depreciation and interest per ton of liquid steel

$$= \frac{11{,}750 \times 20}{181{,}440} = 1s.\ 3\tfrac{1}{2}d.$$

Estimated Working Costs per Ton of Liquid Steel

Cost of Repairs and Stores.—The repairs on a Bessemer plant are very extensive, and include all the materials and labour expended in preparing the material for use in the converters, such as linings and bottoms, the cupola linings and ferro-manganese and lime furnace linings, ladle and chute linings, etc. The repairs also include the materials and labour upon all the plant and buildings, such as the engines, cranes, trucks, conveyors, hoists, permanent-way weighbridges, etc., and all staging, structural steelwork, and buildings.

Stores include all hand-tools, brushes, waste, asbestos, packings, grease, oil, and many other miscellaneous items.

Repairs to Converters.—These repairs include the renewal of the linings and bottoms. The bottoms are renewed frequently, lasting sometimes only 20 heats, while 80 heats can be obtained under certain conditions. Wedding[1] states that at Teplitz, Bohemia, where rammed dolomite bottoms were used in which were inserted acid tuyeres, 80 heats were obtained before the bottoms required renewal; the converters had a capacity of 6½ tons. Using similar bottoms at Pottstown, Pa., U.S.A., only 65 heats were obtained; these converters were 10 tons capacity. The difference in the number of heats obtained from one bottom may be accounted for in the kind of material used, as well as in the difference in the quality of the iron converted, and in the operation of the process.

Converter linings last very much longer than the bottoms, *i.e.* from 6 to 18 months; but the cost of repair is very much reduced if suitable handling apparatus is installed for carrying this out. The appliances used at the North-Eastern Steel Works, Middlesbrough (described on p. 153), are most effectual in rapidly dealing with the repairs of the vessels with a minimum of labour.

Other materials used in the repairs of mixers, cupolas, ferro-manganese and lime furnace, etc., do not cost so much as those used for the converters, but, of course, are included in the total, which amounts to approximately 2*s*. 9*d*. per ton of liquid steel.

Other repairs to plant, including wages and materials on hydraulic, electrical, and mechanical plant, also stores such as oil, waste, etc., cost approximately 9*d*. per ton.

$\therefore$ total cost of repairs and stores = 3*s*. 6*d*. per ton of liquid steel.

Cost of Fuel.—Under this item are included coal, coke, oil, producer gas, wood, and other fuels used in heating up the converters before they are charged with molten metal, for melting the spiegeleisen in the cupolas, for heating the lime and ferro-manganese, heating mixers, drying bottoms in ovens, and all other fuel used for heating purposes about the plant. The average cost is approximately 5*d*. per ton of liquid steel.

Cost of Labour.—The labour of all men required about the plant is included, except the labour already allowed for under "Repairs." The number of men required in handling the raw materials is comparatively few in a well-equipped plant. The following list includes most of the men :—

The loco men engaged in taking the metal from the blast furnaces to the mixers, and from the mixers to the converters.
The weighbridge men outside the mixer and converter houses.
The crane men in mixer and converter houses.
The men at the mixers.
The men at converters, cupolas, ferro-manganese and lime furnace.
The men employed handling scrap and lime, ferro-alloys, etc., for the cupolas and converters.

[1] Wedding, "Basic Process," p. 215.

Men removing slags.

Blast engine and small blower attendants, firemen at boilers, etc., and general labourers.

Foreman.

The total average wages is approximately 1*s.* 9*d.* per ton of liquid steel.

The rates of wages vary in different countries, but the following particulars issued recently in a Bulletin of the American Association of Commerce and Trade, Berlin, giving the rates of wages paid to men employed in the Basic Bessemer process in Germany, are interesting, and give the wages paid on time or day work, and on a tonnage basis. British rates are from 10 to 20 per cent. higher, and American rates from 80 to 150 per cent. higher, than the German rates.

TABLE LVIII

WAGES PAID IN BASIC BESSEMER PROCESS

Kind of labour.	Average wages per day of 12 hours.[1]		Average wages per day on tonnage basis.	
	s.	*d.*	*s.*	*d.*
Foreman	10	0	12	6
Blowing engine engineer	8	6	11	0
Lime and dolomite men	4	3½	5	9½
Stampers	4	3½	5	9½
Masons	4	3½	5	9½
Iron, slag, and chip carriers	3	9½	5	2½
Mixer men	4	2½	5	8½
Converter men	4	9½	6	0
Furnace men	4	10½	6	0
Casting pit men	4	10½	6	0
Helpers	4	1	4	6
Machinists	4	0	5	2½
Cranemen	4	0	5	2½

Cost of Power.—The cost of power consumed in generating the blast for the converters is dependent in some measure upon the kind of fuel used. In Chapter XVI the principal present-day large types of blowing engines are considered, and the amount of fuel used per ton of liquid steel by each class of engine is given. The use of steam engines of both the horizontal and vertical type is common, and the fuel cost for a plant of the size now being considered, when coal is taken at 10*s.* per ton, = about 1*s.* The power consumed by pumps and auxiliary apparatus such as electric and hydraulic cranes and hoists is approximately 2*d.* per ton.

$\therefore$ total power cost = 1*s.* 2*d.* per ton of liquid steel.

Cost of Raw Materials.—The cost of raw materials used in the charge of the basic converter varies considerably, according to the composition of the basic pig and the final product required, the kind of fluxes used, the process adopted, and many other considerations in the working of the process. An approximation, on the basis of an average cost, is all that can be given, with illustrations of individual examples.

Material from Blast Furnace to Mixer.—The cost of liquid iron as supplied to the mixer varies with the prices of the ores, fuel, and other materials, which fluctuate from time to time. When the native ores in Luxemburg and Lorraine cost respectively 5*s.* 10*d.* and 5*s.* 4*d.* per ton, the price of pig iron per ton was 42*s.* 8½*d.* and 44*s.* 9½*d.*, as set forth in the following details given by Wedding[2]:—

[1] In some localities the 8-hour shift is being introduced. [2] Wedding, "Basic Process," p. 184.

	Luxemburg.		Lorraine.	
	s.	d.	s.	d.
Native ores	5	10	5	$3\frac{1}{2}$
Foreign ores	8	4	8	4
Limestone	–	–	0	11
Coke	22	0	23	$6\frac{1}{2}$
Wages	3	$1\frac{1}{2}$	3	$1\frac{1}{2}$
Miscellaneous	3	5	3	$6\frac{1}{2}$
Total	42	$8\frac{1}{2}$	44	9

At the same time, in 1882, the cost per ton of iron in other districts of Germany was as follows:—

Saar district, 47*s.* 11*d.*; Westphalia, from 48*s.* $11\frac{1}{2}$*d.* to 54*s.* 2*d.*

For cost of producing Bessemer pig iron in America during 1902–1906, see Table XIV, p. 16.

Towards the end of the nineteenth century, Jeremiah Head and A. P. Head estimated[1] that the cost of pig iron at Pittsburg, Pa., U.S.A., was £1 12*s.* $5\frac{1}{2}$*d.* per ton, while at Middlesbrough it was £2 12*s.* 2*d.* per ton. Since then, the cost of production in the U.S.A. has increased considerably, while in Britain the price has been reduced. In 1898, to produce 1 ton of pig iron in America cost £1 19*s.*, and in 1908, £2 18*s.* $4\frac{1}{2}$*d.* The increase in American costs is due to several causes, namely, ore having to be obtained from a greater depth, higher wages, increased cost of fuel, limestone, and transit.

From the foregoing it will be evident that the price per ton of liquid iron varies in different countries at the same and different periods. The figure of 50*s.* per ton is therefore taken as an average approximation.

Other Materials.—The amount of lime used per ton of steel varies from 10 to 20 per cent. Taking 15 per cent. as an average—that is, 336 lbs. per ton—the cost per ton of steel, with lime at 14*s.* per ton = 2*s.* 1*d.* approximately.

Ferro-manganese and spiegel for ingot iron cost approximately 1*s.* 6*d.* per ton of steel.

Other miscellaneous materials such as aluminium, ferro-silicon, etc. = 6*d.* per ton.

Summary of Costs

Cost of Plant, £90,000.

	£	s.	d.
Depreciation and interest	0	1	$3\frac{1}{2}$
Repairs and stores	0	3	6
Fuel	0	0	5
Labour	0	1	9
Power	0	1	2
Lime	0	2	1
Ferro-manganese, spiegel, etc.	0	2	0
Pig iron (liquid from blast furnace)	2	10	0
General expenses	0	0	9
Cost per ton of liquid steel	3	2	$11\frac{1}{2}$
Plus 15% loss of iron during conversion	0	7	6
Total cost of production	3	10	$5\frac{1}{2}$
Less value of slag	0	3	6
Total net cost per ton of liquid steel	£3	6	$11\frac{1}{2}$

[1] "Engineer," vol. cvii, p. 471.

The following are given as comparative costs:—

Cost of Converting Basic Iron to Steel in Germany[1]

	£	s.	d.		£	s.	d.
Ferro-manganese or spiegel	0	2	7	to	0	5	4
Wages	0	3	2½	,,	0	4	8
Steam coal	0	0	10	,,	0	1	4
Cupola coke	0	3	4	,,	0	4	0
Moulds	0	0	10	,,	0	1	3½
Lime charge	0	0	3	,,	0	2	7
Basic lining	0	3	5	,,	0	4	2
Repairs	0	2	1	,,	0	2	4½
Interest and sinking fund (15%)	0	1	0½	,,	0	1	0½
Miscellaneous	0	4	8	,,	0	5	0
Total	£1	2	3		£1	11	9½

	£	s.	d.
Putting the price of pig iron at 41*s.* 8*d.*	2	1	8
Loss at	0	6	3
Cost of conversion at	1	1	4
One ton of ingot iron costs	£3	9	3
With pig iron at 33*s.* 10*d.*	1	13	10
Loss at	0	5	1
Cost of conversion at	1	11	9½
One ton of ingot iron costs	£3	10	8½

Cost of Converting Basic Iron to Steel at Charleroi, Belgium.[2] **Plant of three 10-ton converters. Output 450 tons in 24 hours**

Metal direct from blast furnace to converters.

	£	s.	d.
Waste of pig iron, 330 to 440 lbs. per ton	0	8	4
Coal, 330 to 364 lbs.	0	1	4½
Coke, 28 to 99 lbs.	0	0	3½
Dolomite, 121 to 132 lbs.	0	1	3½
Lime, 396 to 419 lbs.	0	0	4½
Coal tar, 11 to 13 lbs.	0	0	8
Refractory materials	0	0	9
Plumbago	0	0	3½
Miscellaneous expenses and repairs	0	1	1½
Handling wagons and switching	0	0	1
Wages	0	1	7
General expenses	0	0	5
Sinking Fund	0	0	5
Ferro-manganese, 11 to 13 lbs.	0	1	2½
Total	0	18	2½
Deduct value of slag	0	2	4½
Cost of conversion	0	15	10
Add cost of pig iron	2	1	7
Total net cost per ton of liquid steel	£2	17	5

[1] Wedding, "Basic Process," p. 185. [2] "Revue Universelle des Mines," vol. xv, pp. 1–26.

Estimated Cost of producing Steel in 24-ton Basic Bessemer Plant with Four Converters

Capacity of Plant.—Making allowances for the necessary delays in changing bottoms, patching and renewing linings, and general repairs, the maximum output of three 24-ton converters in constant operation during 24 hours is approximately 2000 tons,[1] or equal to over 41 heats per 12-hour shift from three vessels. This is above the average proportional output from some smaller plants. Take, for instance, the output from three 10-ton basic converters at the works of the North-Eastern Steel Co., Middlesbrough, which is a good average case, and is given[2] as 34 heats per shift of 12 hours, or approximately 17 per cent. less than the number of heats from the 24-ton converter plant.

The weekly output of the 24-ton plant considered in the following costs is calculated on the basis of $10\frac{1}{2}$ shifts of 12 hours, and is equal to $10\frac{1}{2} \times 1000 = 10{,}500$ tons. Taking 48 weeks per year, the annual output $= 48 \times 10{,}500 = 504{,}000$ tons, say 500,000 tons per year.

Cost of Plant.—The capital expenditure on plant and buildings for the production of the above output is somewhat difficult to estimate without having all the conditions of site and locality in view. The foundations for such a plant may be twice as much on one site as on another, according to the nature of the soil. The cost of the plant and buildings are more easily determined, and from details of costs in our possession we are in a position to make the approximate estimate of £200,000, which may be taken as reliable. This price includes the following plant delivered, erected, and ready for use:—

1. Three mixers, each of 350 tons capacity.
2. Three loco ladle trucks, of 20 tons capacity, for conveying metal from blast furnaces to mixers.
3. Two 40-ton overhead electric travelling cranes, in mixer building, with auxiliary tipping equipment.
4. Two 25-ton electrically tipped and operated ladle trucks, for conveying charge of molten iron from the mixers to the converters.
5. Two weighbridges, for recording the weight of iron received from the blast furnaces at the mixer house, and the metal from the mixers before delivery to the converters.
6. Four 24-ton converters, each mounted on pedestals, with hydraulic tipping gear and complete blast and other valve equipment.
7. Two steam-driven blowing engines of 4000 h.p. each, complete with condensers, boilers, superheaters, economiser, pipes, chimney, crane, and buildings.
8. Two electrically operated tilting ladles of 25 tons capacity, for taking the steel from the converters to the casting pits.
9. One 35-ton overhead electric travelling crane for serving the converters.
10. Two trucks with special hydraulically operated tops, used for taking the bottoms from converters.
11. Six slag pan skips mounted on trucks, for conveying slag from converters to the slag mill.
12. Two cupolas for melting spiegeleisen.
13. One low pressure blower for cupolas.
14. Three tipping ladles on trucks, each of 2 tons capacity, for removing melted spiegel to converters.
15. One ferro-manganese and lime furnace.

[1] This has been confirmed by a private authority.
[2] "Iron and Coal Trades Review," vol. 77 (2), p. 1455.

16. Two hoists to cupola staging.

17. All stagings, fittings for converters and cupolas, piping, valves, appliances, tools, conveyors, etc.

18. Two sets of hydraulic pumps with accumulator, for supplying the converters, trucks, and all appliances under water pressure about the plant.

19. Buildings for converter, mixer, and dolomite plants.

20. All crushing, grinding, and drying plant for dolomite shop.

21. All foundations for buildings and plant.

22. Miscellaneous items of plant.

Blast furnaces are not included in this cost.

Depreciation and Interest on Plant.—Allowing the same rate of depreciation as in the smaller plant, namely, 10 per cent. on plant, 5 per cent. on buildings, and $2\frac{1}{2}$ per cent. on foundations, together with 5 per cent. interest on the total capital outlay, the following annual charge is made on this account:—

	£
Depreciation on plant: 10% of £130,000	13,000
„ „ buildings and structural work: 5% of £50,000	2,500
„ „ foundations: $2\frac{1}{2}$% of £20,000	500
Interest on capital: 5% of £200,000	10,000
Total annual charge for depreciation and interest . . .	£26,000

Charge for depreciation and interest per ton of liquid steel

$$= \frac{26{,}000 \times 20}{500{,}000} = 1s.\ 0\tfrac{1}{2}d.$$

Working Costs per Ton of Liquid Steel.—The items of cost in the working of a large plant are similar, although different in amount, to those of a small one. When it is remembered that 24 tons of steel can be converted as rapidly as 10 tons, the labour involved per ton of steel produced is very greatly reduced, even when the two plants are equipped with the same handling devices for bringing the materials to and from the converter plant. In a well-managed plant, one man can operate a 100-ton crane as easily as one of 10 tons lifting capacity, and like results are obtained with the other heavier handling appliances where the duplication of the human element is unnecessary. Extra labour, however, is required in operating additional machines in the preparation and handling of materials for the repairs of vessels, etc., but not in the ratio of 24 : 10.

We are not in possession of the actual details of cost of operating a 24-ton converter plant, but have, on good authority, that the conversion costs are from 8*s*. to 10*s*. per ton of steel produced, including the following items:—

1. All repairs to converters, cupolas, mixers, and auxiliary plant, including the preparation of the basic materials for the linings and bottoms of converters, linings and repairs of cupolas and mixers, furnaces and ladles. Mechanical, hydraulic, and electrical repairs to plant, and all structural and other miscellaneous repairs in connection with the maintenance and operation of the plant. All stores are likewise included.

2. All fuel for heating purposes, such as coal, coke, producer gas, oil, wood, and other fuels used in heating the converters and mixers, furnaces for roasting and ovens for drying the refractory materials, and all other fuels used in aid of steel production. The amount of fuel used for these purposes is less per ton of steel produced than in the small plants, as the output of steel is so much greater during the period in which the plant is kept in constant operation.

3. Labour includes all wages and a percentage of salaries. In operating a

24-ton plant, the labour costs are from 30 to 50 per cent. less per ton than that of a 10-ton plant.

4. All power used in generating the blast for converters, cupolas and mixers, hydraulic pumps, electric cranes, conveyors, hoists, steam and electric ladle trucks, tipping devices, etc. The principal item of power is that of generating the blast for the converters, and may be taken at approximately 6*d.* to 9*d.* per ton of steel produced, according to the type of engine employed.

5. All raw materials such as lime, fluorspar, ore, scale, and scrap, also the additions made to charge in the form of ferro-manganese, spiegeleisen, etc.

6. Depreciation and interest on plant, to which reference has already been made.

Taking, therefore, the figure of 9*s.* 6*d.* for the transformation cost per ton of liquid steel, the following summary represents the total cost per ton of steel :—

Summary of Costs

Cost of Plant £200,000.

	£	s.	d.
Depreciation and interest; Repairs and stores; Fuel; Labour; Power; Raw materials (other than pig iron)	0	9	6
Pig iron (liquid from blast furnace)	2	10	0
Cost per ton of liquid steel	2	19	6
Plus 15% loss of iron during conversion	0	7	6
Total cost of production	3	7	0
Less value of slag	0	3	6
Total net cost per ton of liquid steel	£3	3	6

CHAPTER XVIII

COMPOSITION OF CHARGES EMPLOYED AND ANALYSES AND USES OF STEEL PRODUCED IN LARGE BESSEMER PLANTS

Acid-lined Converters

In the conversion of molten iron to steel in the acid process, it is necessary to select pig irons which have sufficient heat-giving elements to produce the necessary chemical reactions during the process, as no external heat is added to the initial heat of the iron. In Table VIII, p. 13, typical analyses of several brands of Bessemer pig irons are given, which will produce singly or when mixed together, satisfactory results in the acid-lined converter. The analyses are only typical, as many hundreds of brands of pig iron exist which are suitable for the process, although they may vary to some degree in general analysis. The principal heat-giving elements in the iron are carbon, silicon, and manganese, but as the silicon and manganese are oxidised during the first period of the blow while the temperature is low, it is necessary that sufficient of these elements are present to allow of the temperature rise to encourage the oxidation of the carbon without undue loss of iron. Pig iron can be used with satisfactory results under certain conditions, when containing silicon varying from 0·75 to 4·0 per cent., and manganese from 4·0 to 0·5 per cent. This shows the flexibility of the process which admits of such wide variation in the analyses of the materials used.

As phosphorus and sulphur are not oxidised in the acid process, it is necessary to avoid using materials containing percentages of these elements in greater proportion than can be tolerated without interfering with the ductility of the finished product. During the process of conversion, from 7 to 9 per cent. of waste takes place, which tends to increase rather than diminish the amount of phosphorus and sulphur in the charge.

The principal difference in the acid and basic processes lies in the fact that phosphoric pig irons can be used only in the latter process. As phosphoric iron ores are more abundant throughout the world than non-phosphoric iron ores, the basic process has been of more service to countries such as Germany and France, where the ores contain large percentages of phosphorus.

The molten pig iron used in the acid as in the basic converter, is taken either direct from the blast furnace to the converter, or to the mixer for desulphurisation, and thence to the converter. In some works the old practice of remelting different brands of pig iron in cupolas and taking the metal from the cupola to the converter is still adopted. In any case the converter is usually heated very well with coke fanned with a gentle blast before the metal is poured into the converter.

Uses of Acid Bessemer Steel.—Steel made from the acid Bessemer process is now used for almost every purpose for which open-hearth steel is employed

(see Table XCI, Chapter XXXVI). Prejudice only has set limitations upon the process which are gradually being removed. The early experiences with steel manufactured in the Bessemer converter caused much opposition to its liberal use.

Composition of Charges.—

Charge I. Low Manganese.

The following details[1] of a heat which, though made on November 13th, 1879, at the Bethlehem Steel Works, U.S.A., is in many respects like an average British charge. The molten pig iron used contained the following: C, 3·56 per cent.; Si, 2·39 per cent.; Mn, 0·49 per cent.; P, 0·089 per cent. Several brands of pig irons (made in different blast furnaces from a variety of iron ores in which were included limonite, red and brown hematite, magnetite, and specular) were remelted in a cupola to make up the charge for the converter. The spiegel was melted in furnaces and added to the charge in the converter.

Weight of charge—

Molten metal in ladle	16,000 lbs.
Scrap (bloom ends, etc.)	800 ,,
Spiegel (16% Mn)	2,000 ,,
Ferro-manganese (36% Mn)	40 ,,
Total charge in converter	18,840 lbs.

Weight of steel produced—

Ingots	16,720 lbs.
Castings	480 ,,
Scrap	300 ,,
Total	17,500 lbs.

Loss of metal by conversion 7·112%.

	C	Si	Mn	P	
Analysis of pig iron	3·56	2·39	0·49	0·089	per cent.
,, ,, scrap	0·264	0·117	1·229	—	,,
,, ,, steel produced	0·367	0·06	1·175	0·0897	,,

Time taken	18 minutes.
Pressure per square inch	$28\frac{1}{2}$ to $23\frac{1}{2}$ lbs.

Charge II.

The following is a typical American charge as carried out at the Illinois Steel Company's Works, Chicago, producing rail steel:—

Weight of molten metal charged to converter	21,500 lbs.
Steel scrap added before the blow	1,000 ,,
Steam used for cooling charge, equivalent to steel scrap	800 ,,
Spiegel	2,500 ,,

	C	Si	Mn	P	S	
Analysis of pig iron	3·10	0·98	0·40	0·10	0·06	per cent.
,, ,, scrap	0·36	0·08	0·97	0·10	0·08	,,
,, ,, steel produced	0·45	0·038	1·15	0·109	0·059	,,

[1] "Transactions American Inst. of Mining Engineers," vol. 9, p. 259.

Time taken	9 mins. 20 secs.
Pressure	27 lbs. per square inch.

Many more charges could be given, but there is little variety in them except in the composition of additions made, depending upon the quality of the steel required.

Basic-lined Converters

Contrary to the practice in the acid process, pig iron with a low silicon content and high in phosphorus is found most suitable for the basic process. Silicon, the valuable heat-giving agent in the acid process, is replaced by manganese in larger proportions in the basic iron. A considerable range in the percentages of phosphorus and manganese in basic iron is admissible, while the silicon must be kept as low as possible. Phosphoric irons vary considerably in analyses in different countries, as shown in Table VII, p. 12.

In Germany, where more steel is manufactured by the basic process than elsewhere, the native iron ores favour the production of the most suitable pig iron for the process. In Britain, basic iron is not so easily produced, it being necessary to import foreign manganese ores to mix with English ores before the pig iron can be made sufficiently high in phosphorus and manganese for the ordinary basic process. This puts Britain at a disadvantage with her Continental rivals in making steel by this process. In America, the basic Bessemer process is not used at all, the ores being unsuitable on account of the insufficiency of phosphorus contained in them.

Uses of Basic Bessemer Steel.—For many years steel produced either by the Basic Bessemer or Basic Open-hearth processes did not find favour in this country. The unsuitability of the native ores, the irregularity of the composition of the pig iron produced therefrom, and the uncertainty of the results obtained from the furnaces, told against the adoption of basic steel for bridges, ships, railroads, and most kinds of structural work. Even after basic open-hearth steel was accepted by many users and engineers, distrust in the results from the basic Bessemer retarded the development of the latter. The variable results obtained were traced to the want of regular control of the phosphorus throughout the process. Improvements in the methods of fluxing have made it possible to obtain more reliable steel, with the result that the increase in its manufacture has been very considerable during recent years.

In Germany, where the largest amount of basic Bessemer steel is made, 8,030,571 metric tons were produced in 1910.[1]

Steel for all kinds of purposes, some of which was formerly produced by the crucible process only, is now made regularly by the basic Bessemer process. The following are some of the uses: Rails, tyres, axles, boiler and ship plates, tin plates, girders and all kinds of bridge and structural sections, wire, bolts, locomotive and other kinds of boiler tubes, rolled tubes and forgings of every description.

Composition of Charges.—The charges of the basic Bessemer consist of liquid iron taken from the mixer direct to the converter or from the cupola after the pig iron from the blast furnace has been remelted. See Table VII, p. 12, for analyses of various pig irons. According to Wedding, the best pig iron for the basic process is made at Ilsede, Germany, and has the following analysis :—

Phosphorus, 3 per cent.; manganese, over 2 per cent.; silicon, 0·5 per cent.; sulphur, less than 0·1 per cent.

[1] "Mineral Industry," 1911, p. 429.

TABLE LIX

CHARGES AND ANALYSES OF STEEL PRODUCED AT WITKOWITZ

Charge No.	Kind of steel.	Analysis of pig iron used.					Recarburising additions.			Chemical composition of steel.						Mechanical tests.		
		Si %	Mn %	P %	S %	Cu %	Spiegel. Si 0·18% Mn 13·8% P 0·11%	Ferro-manganese 73% Mn	Grey Bessemer pig. Si 1·43% Mn 2·51% P 0·15%	C %	Si %	Mn %	P %	S %	Cu %	Tenacity. Tons per square inch.	Elongation % on 3·937″ (100 mm.).	Reduction of area. %
1	Moderately hard rail steel	0·54	1·0	1·95	0·23	0·06	0·6%	0·6%	When over 1·0% Mn required in rails, 7½% of above used	0·45	trace	—	0·04	0·06	0·07	37·1 to 40·1	20 to 20·5	51·5 to 36·9
2	Ingot iron for plates, axles, angle iron and rivets	0·11	1·16	3·46	0·09	0·02	—	1% of 50% FeMn	—	0·19	trace	0·34	0·04	0·04	0·02	28·6 to 31·75	25 to 20	64 to 55
3	Ingot iron for telegraph wire and stamped ware	0·62	1·38	2·0	0·08	0·09	—	—	—	0·06	0·00	0·3	0·02	0·03	—	22·9 to 24·8	37 to 33	77 to 72

Scrap steel is sometimes mixed with the charge of pig iron, either in the cupola during re-melting, or in the converter while the blow is proceeding. The proportion of scrap steel to pig iron rarely exceeds 10 to 15 per cent.

With each charge of pig iron, considerable additions of lime are necessary. In the early years of the process the only fluxing agent used was lime, and as a rule it was charged into the converter red-hot before the liquid iron was poured in. During later years, lime was added in varying amounts at different stages of the blow, and more recently, lime with oxides of iron in different forms and amounts, has been used with success.

The following charges and analyses give an idea of the raw materials employed in, and the products obtained from, basic Bessemer converters.

(1) The table of charges, analyses, and tests given on p. 188, is prepared from the results of some of the earliest work done in basic-lined converters at Witkowitz, in Austria.[1]

(2) At Teplitz, in Bohemia, charges of the following compositions were used :—

Pig iron . . .	6·5 tons.
Lime	1870 lbs., added before the iron.
Steel scrap . .	800 to 1600 lbs., added during the blow.

To the blown metal was added physics given in the following table against the grade of steel named :—

TABLE LX

PHYSICS ADDED TO CHARGES AT TEPLITZ

Kind of steel.	Physics added. Percentage of weight of charge.		
	Spiegeleisen, 12 % Mn.	Ferro-manganese, 70 % Mn.	White iron.
Softest grades of mild steel . .	1 %	0·5 %	—
Rail steel	7 %	—	—
Steel castings.	3 %	0·5 %	4 %

The physics are added red-hot and solid, spiegel and white iron to the converter, and ferro-manganese to the ladle.

(3) Charges where lime is added in two operations.

At several German works a modification of the ordinary method of adding all the lime at the commencement of the blow was used with great success for many years. In 1886, Professor C. Scheibler[2] introduced it at Hörde, Rührort, and Meiderich in Westphalia. At the Phœnix Works, the lime used for a 12-ton charge was reduced from 1·8 ton to 1·28 ton, or nearly 33 per cent. less than the amount formerly used. The total lime used is added in two portions, $\frac{2}{3}$ before charging the metal (the slag formed being poured off after blowing 3 to 4 minutes) and the rest of the lime added during the after-blow.

From the 12-ton charge of metal used at the Phœnix Works, when the whole of the lime was added at one time, the average weight of slag produced per 10·2 tons of ingots was 2·7 tons, containing 15 per cent. of phosphoric acid, the slag being valued at £1 per ton. By adding the lime in two portions, the total weight of slag is reduced, but its value is increased.

[1] "Journal Iron and Steel Institute," 1881, II, p. 397.
[2] "Stahl und Eisen," 1894, p. 1097.

The following analyses of the 1st and 2nd slags, with their values, are interesting:—

TABLE LXI

Analyses of Slags, Phœnix Works

	Quantity. Tons.	P_2O_5 %	SiO_2 %	CaO %	Mn %	Fe %	Value. Per ton.	Value. Total. £ s. d.
1st Slag	0·725	23·79	5·17	50·09	6·16	6·54	39/-	1 8 3
2nd Slag	1·465	16·69	3·11	47·06	5·02	19·29	22/-	1 12 3
Total	2·190							3 0 6

The saving per ton of ingots is summed up thus—

Lime saved, 0·051 ton @ 11*s*. per ton	6·72 pence
Diminished waste, 0·0048 ton @ 60*s*. ton . . .	3·46 „
Improved value of slag	7·56 „
Total per ton of ingots . . .	17·74 „

(4) The following charge and analyses of steel produced at the Kladno Works, Bohemia, are given by Mr. C. Stöckl[1]:—

Pig iron	12 tons.
Scrap	1 ton.

Additions to converter . .	Ferro-manganese (80% Mn) . .	90 to 130 lbs.
Additions to ladle	Spiegel (10% Mn)	290 lbs.

The amount of lime used is not given by Mr. Stöckl, but Wedding gives the following for a 6-ton charge at the Kladno Works, *i.e.* 2000 lbs. of lime, mixed with 300 to 360 lbs. of coal.

The steel produced from five successive charges give the following percentage analyses:—

Carbon	Manganese	Phosphorus
0·07	0·107	0·047
0·08	0·217	0·057
0·08	0·126	0·023
0·07	0·229	0·051
0·08	0·143	0·018

(5) High silicon phosphoric pig iron charges.

As the result of suggestions from Dr. O. Massenez of Wiesbaden, regarding the use of ordinary Cleveland pig iron in the basic converter, Mr. Arthur Windsor Richards[2] made several trials at the works of Messrs. Bolckow, Vaughan and Co., Ltd., which met with success, and proved that Cleveland grey pig iron could be used economically. The iron contained—

[1] "Journal Iron and Steel Institute," 1890, I, p. 323.
[2] *Ibid.*, 1907, I, p. 106.

Silicon	1·5 to 3	%
Manganese	0·5 ,, 0·75	%
Phosphorus	1·45 ,, 1·55	%
Sulphur	0·04 ,, 0·06	%

Instead of placing large quantities of lime in the converter before the metal was charged, as is the usual practice when high manganese basic iron is used, iron oxides mixed with a small percentage of lime were substituted. By this means a sufficiently fluid slag was formed in the first part of the blow by the oxidation of the silicon which could be poured off as soon as the carbon flame appeared. The composition of the first slag was—

Iron, 3 % ; silica, 35 to 45 % ; phosphorus, nil.

The final slag gave the following analysis :—

Iron, 8 to 11 per cent. ; phosphoric acid, 14 to 20 per cent. (95 to 100 per cent. soluble in 10 per cent. solution of citric acid in water) ; silica, 11 to 12 per cent.

Mr. Richards states that enormous economies had been effected during the eighteen months he had used his process at Messrs. Bolckow, Vaughan & Co., Ltd. The loss during the blow averaged $12\frac{1}{2}$ per cent. The iron ore used as oxide yielded nearly all its iron to the charge of steel.

While Mr. Richards found high silicon phosphoric basic iron suitable when used in the basic converter as described, Dr. Arthur Cooper[1] of the North-Eastern Steel Works did not meet with the same success.

(6) Briquettes of iron oxides in charges (Dudelange process).

Mr. J. Flohr,[2] at Duedelinger Works, introduced with success the use of briquettes composed of mill scale and other iron oxides mixed with slaked lime, which when pressed and allowed to stand for a few days gave the following analysis :—

Iron shot	1·06 %
Iron oxide	31·4 %
Ferrous oxide	44·7 %
Lime	9·89 %
H_2O	4·16 %
CO_2	0·68 %

These briquettes are used in the place of scrap and lime and other devices for cooling the charge during the blow. Scrap and lime thus employed, not only cool the charge, but reduce the phosphoric acid in the slag when an excess of lime is present.

Using pig iron containing—P, 2·0 per cent. ; Mn, 1·3 per cent. ; Si, 0·5 per cent. ; about 13 per cent. of lime is usually found sufficient to ensure a good dephosphorisation, and this is charged into the converter before the iron, in the ordinary manner.

The briquettes, which weigh about $7\frac{1}{2}$ to 8 lbs. each, are thrown into the converter towards the end of the decarburising period, and have a powerful effect in reducing the time taken during the after-blow to dephosphorise the charge. It is stated that only a few seconds are required to complete the operation.

Dr. Goeren, giving an account of the Flohr improvements, shows that a great saving is effected by the use of the briquettes.

(7). Charges with pig iron having low percentages of silicon and manganese.

[1] "Journal Iron and Steel Institute," 1907, I, p. 109.
[2] "Iron Age," vol. 81, p. 1706.

Below are given two charges upon which investigations were made by Messrs. F. Wüst and L. Laval, which show the variations in the amounts of materials used.

Charge 1.		Charge 2.	
Pig iron	23,093 lbs.	Pig iron	23,721 lbs.
Lime	293 „	Lime	3880 „
Ferro-manganese (76·7 %)	154 „	Ferro-manganese (76·7 %)	132 „
Ferro-silicon (48·3 %)	44 „	Ferro-silicon (48·3 %)	nil
Scrap	nil	Scrap	617 „
Spiegel	1543 „	Spiegel	nil

Additions to the Blown Metal.—As the metal in the basic converter is brought to the same constitution at the termination of the blow as the metal blown in the acid-lined bottom-blown converter, the amount and character of the physic additions necessary to produce any desired steel are the same in both processes. As a rule, only traces of carbon and manganese, and no silicon, are found in the blown metal, while sulphur and phosphorus are reduced to 0·03 to 0·06 per cent. and 0·05 to 0·08 per cent. respectively, according to the quality of the basic iron used in the charge.

The materials used for both mild and harder carbon steel ingots are spiegel and ferro-manganese. These are added to the blown metal in the converter in the solid form, previously heated as in the acid process. It is found that the action is not so violent when the spiegel is added solid as when melted; the former method is therefore generally adopted. The ferro-manganese is also heated and added to the ladle while the contents of the converter are poured therein.

Loss of Material during the Blow.—This depends upon the quality of the basic iron, lime, and other fluxing agents, and the duration and condition of the blow. In basic pig iron the carbon is mostly found in the combined state, and is less than in the non-basic pig iron. It does not often exceed 3·5 per cent., and is usually about 3 per cent. Taking the carbon at 3·5 per cent., and assuming the analysis of the basic metal in the converter before blowing to be as given below, the loss in removing the metalloids is:—

Carbon	3·5 %
Silicon	0·5 %
Manganese	2·0 %
Phosphorus	2·5 %
Total	8·5 %

During the removal of these elements, there are other losses due to the oxidation of the iron in the slag formation and in the ejection of iron, which amount to from 4 to 5 per cent. of the weight of the charge. The total loss is therefore about 13 to 14 per cent.—in general practice the loss is found to vary from 13 to 18 per cent. As against this loss there is the gain from the phosphoric slags, which are sold for agricultural purposes.

CHAPTER XIX

MODERN 2-TON BOTTOM-BLOWN BESSEMER PLANT FOR STEEL FOUNDRIES

FOUR 2-TON CONVERTER PLANT

General Description.—The bottom-blown plant illustrated in Fig. 97 is that of a two 2-ton converter plant. By duplicating the plant shown, four converters can be arranged in one line.

The converter vessels are mounted on pedestals with roller bearings, and are tipped either by an electric motor through suitable gearing, or by hand; in fact both electric and hand drives are used. (As an alternative, hydraulic tipping gear is sometimes provided.) The controllers for operating the vessels are suitably placed in front of the converters, so that the operator may have the vessels all within view.

Arrangement of Converters.—The converters are placed in one line in front of the cupola staging, from which the hot metal is supplied to them after being weighed. Each pair of converters is coupled with a central blast pipe from the blowing engine. A central valve is placed between them to admit air to either of them as desired, and the blast is carried to the tuyere bottom in the ordinary way. The blast pipes are fitted with non-return flap valves and stop valves.

Blowing Engine.—Only one blowing engine is required for the four converters, as the rate of blowing is much faster than in the surface-blown plant and there is not the same necessity for both vessels to be in operation at the same time. It will be observed that with this plant, a blowing engine is used instead of a high-pressure blower, as the pressure is so much higher per square inch than with the surface-blown plants. In the following cost, a steam-driven blowing engine has been included, although steam, gas, or electrically driven blowing engines may be used. (See Chapter XVI for descriptions of various types of Converter Blowing Engines.) Low pressure Roots' Blowers are employed for the cupolas.

Cupolas.—Four cupolas are arranged on the staging, together with weighing ladle and appliances, all of which are similar in design and capacity to those used in the surface-blown plant described in Chapter XX, except the weighing ladle, which is made to tip, instead of being tapped.

Operation of the Plant.—This is similar in every respect to the surface-blown plant, except in the method of charging the converters, and in the rate of blowing. As the tuyeres are in the bottom of the vessel, the hot metal must be poured into it while it is lying in a horizontal position. After the metal is weighed, it is poured into the converter from the ladle; and while the converter is being turned into the vertical position the blast is applied, and the operation of blowing commenced forthwith. The progress of the blow differs only from that of the surface-blown plant in the rate of oxidation of carbon, silicon, and manganese, and is more rapid under the higher pressure of air passing through

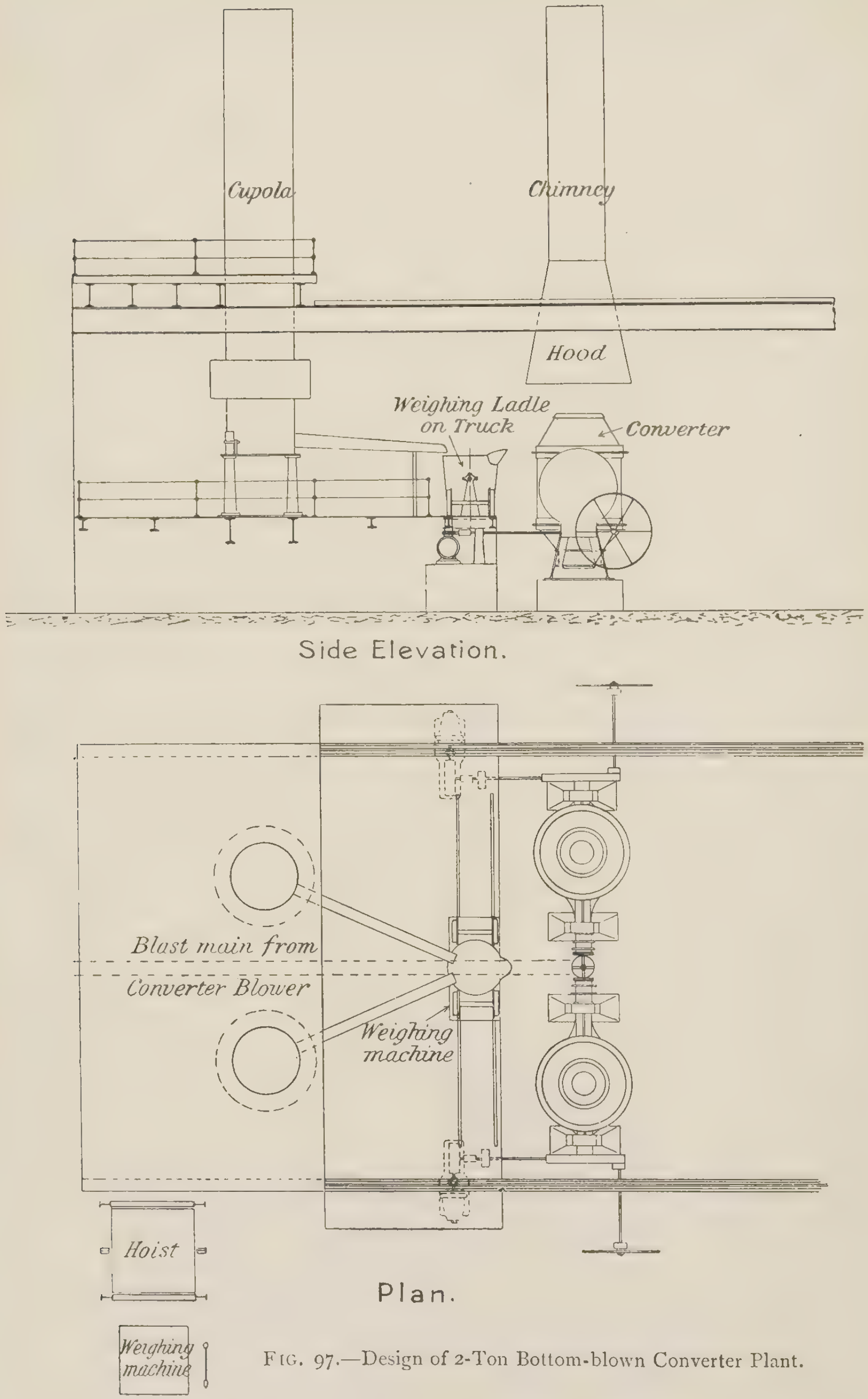
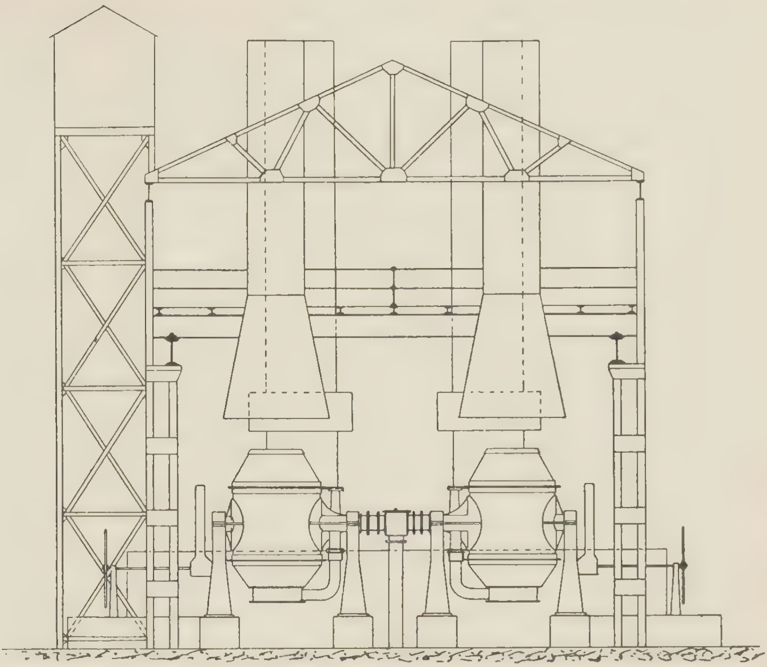


FIG. 97.—Design of 2-Ton Bottom-blown Converter Plant.



Front Elevation.

FIG. 97.

the body of the metal. The time usually taken to complete a blow is from 10 to 20 minutes.

Output and Cost of Plant.—The cost of steel is based upon a maximum average output from the plant working 10 hours per day. Two vessels are in constant use, one following the other, *i.e.* while one is being charged the other is being "blown." The blast is therefore changed from one to the other alternately. While two vessels are in use, the idle ones are being repaired for use the following day. Allowing 20 to 25 minutes for each heat, it would be possible, with continuous working and no mishap, to obtain 28 heats from the two converters per day.

The following items are included in the cost of £11,000, which covers approximately the whole installation:—

Four 2-ton converters, mounted on pedestals, each arranged with tipping gear operated by electric motor, and with hand gear, together with the necessary electric controllers and switches. Each converter to have the air carried through one trunnion to the blast box on the bottom of the vessel.

Four cupolas of the same capacity and with the same accessories for rapid melting as those used with the surface-blown plant.

One high-pressure, steam-driven blowing engine, to supply the necessary blast to the converters, together with all piping, valves, and gauges.

Two steam boilers and necessary accessories for supplying steam to blowing engine.

Two low-pressure Roots' Blowers, each coupled direct through gearing to an electric motor mounted on an extension of the bed-plate of the blower,

for supplying the blast required for the cupolas. Each to work independently.

One electrically-driven lift, with motor and gearing, controllers, etc., complete.

One weighbridge, with the latest improvements for weighing the materials.

One weighing machine, for weighing charge from cupolas.

One ladle and carriage, with motor and gear for operating them to and from the cupolas, weighing machine, and converters.

One high-speed jib crane, for operating in front of the ladle pits.

Two overhead cranes, for serving the foundry with molten steel.

All structural steel work, including stagings for cupolas and suitable roofing.

Four hoods and chimneys for converters.

One coke-fired crucible melting furnace, with three 4-pot melting holes for melting additions to charge.

One small cupola for melting additions, with necessary pipe connections from the blast mains of the larger cupolas.

One small furnace for heating ferro-alloys when added to charge in the solid state.

One set of ladles, including two 10-ton ladles and six 3-ton ladles.

Blower house, with the necessary switchboard equipment for the complete plant.

All wiring, switches, starters, and electrical accessories complete.

All blast pipes, spouts, chutes, slag and coke pans, tipping trucks, tools, etc.

All brickwork, concrete foundations, pits, linings for converters, cupolas, and ladles.

The whole plant erected complete and set to work.

It is assumed that the electrical power for the motors is supplied to the switchboard from an outside source, the cost of which is not included in the above figures.

Half the value of the two overhead cranes is included in the above cost.

Allowing a depreciation of 10 per cent. on the complete steel plant, 5 per cent. on the buildings, and $2\frac{1}{2}$ per cent. on the foundations, the annual charge for depreciation is :—

£8000 @ 10 %	£800
£1000 @ 5 %	£ 50
£2000 @ $2\frac{1}{2}$ %	£ 50
Total	£900

$$\text{Interest on capital} = 5\ \%\ \text{of}\ £11{,}000 = £550$$

$$\therefore\ \text{annual charge for interest and depreciation} = £1450$$

With an annual output of 15,000 tons of steel in the ladle, the charge for depreciation and interest per ton of liquid steel

$$= \frac{1450 \times 20}{15{,}000} = 1s.\ 11d.$$

Working Costs (per Ton of Liquid Steel for Carbon Steel Castings)

Cost of Repairs and Stores.—This cost includes all labour and materials spent in the repair of converter bodies and bottoms, cupolas, crucible furnace, ladles, boiler, and general repairs about the plant. It also includes the various stores used.

The average cost of repairs and stores taken over a period of twelve months, including materials and labour, is 4*s*. 6*d*. per ton of liquid steel.

Cost of Fuel.—As the materials melted in the cupola are the same as those used in the surface-blown plant, the quantity of coke consumed in the cupolas is the same per ton of material melted. Equal amounts of coke are used in heating the converters and in melting physic in both plants. The total averages $3\frac{1}{2}$ cwts. per ton of liquid steel in the ladle. Taking coke at 22*s.* 6*d.* per ton, the cost of fuel per ton of liquid steel = 3*s.* $11\frac{1}{2}$*d.*

Cost of Labour.—All men employed in working the plant are included in this cost except the labour already included under "repairs." The men required are :—

Four converter men.
Two cupola attendants.
Two cupola chargers.
Eight cupola charge wheelers.
One man in charge of blowing engine, blowers, etc.
One man in charge of physic cupola.
One man at boiler.
Two men at crucible furnace.
Five men patching, repairing, and operating ladles.
One man at jib crane and part wages of two men on overhead cranes.
One foreman "blower."

Total wages for one week	£56 10*s.*
Steel produced in ladle in one week . . .	320 tons

$$\therefore \text{ cost per ton of liquid steel} = \frac{56 \cdot 5 \times 20}{320} = 3s.\ 6\tfrac{1}{2}d.$$

Adding 50 per cent. as part expenses of chemist and management = 1*s.* 9*d.* per ton—

the total cost of labour per ton of liquid steel = 5*s.* $3\frac{1}{2}$*d.*

Cost of Power.—The cost of power includes steam used in blowing engine and jib crane, electric power for cupola blowers, tipping converters, lift, and half-current consumed by overhead cranes.

Electric power for one week = 4800 units = 15 units per ton.

	s.	*d.*
With current at $\frac{1}{2}$*d.* per unit, cost of electric power per ton =	0	$7\frac{1}{2}$
Cost of steam power per ton . . . . =	1	$11\frac{1}{2}$
∴ Total cost of power per ton of liquid steel . =	2	7

Raw Materials.—Taking the same weights and prices of raw materials as used in the surface-blown Bessemer plant, the total cost of raw materials for one week = £1177 18*s.* 4*d.*

∴ With a weekly output of 320 tons of liquid steel, the price of raw materials = £3 13*s.* 8*d.* per ton.

Summary of Costs

Cost of plant £11,000.

	£	*s.*	*d.*
Depreciation and interest	0	1	11
Repairs and stores	0	4	6
Fuel	0	3	$11\frac{1}{2}$
Labour + 50 % for management	0	5	$3\frac{1}{2}$
Power	0	2	7
Raw materials	3	13	8
Total cost per ton of liquid steel . . .	£4	11	11

The cost per ton of liquid steel in the surface-blown plant of the same capacity, melting and converting the same raw materials, is £4 9*s.* 10*d.*, as against £4 11*s.* 11*d.* above. This increase, it will be observed, is due to higher cost of repairs, labour, and power. With vessels of larger capacity, this cost would be correspondingly reduced.

Two 2-Ton Converter Plant

In a two 2-ton converter plant, as shown in Fig. 97, two cupolas are used instead of four. The staging and other structural work are also reduced accordingly. One overhead crane serves the plant instead of two. In other respects the equipment is about the same size. This means that the cost for a two-vessel plant is considerably over half that of a four-vessel plant. There is, however, a slight compensation in the output, which can be increased in the ordinary working day of 10 hours from 14 to 18 heats from one converter. Calculating, however, upon the former basis of output, the following is the cost of one ton of liquid steel in the ladle.

Summary of Costs

Capacity of plant, 160 tons per week.
Cost of plant, £8000.

	£	*s.*	*d.*
Depreciation and interest	0	2	4½
Repairs and stores	0	4	8
Fuel	0	4	6
Labour + 50 % for management	0	6	9
Power	0	2	9
Raw materials	3	13	8
Total cost per ton of liquid steel	£4	14	8½

CHAPTER XX

MODERN 2-TON SURFACE-BLOWN CONVERTER PLANT FOR STEEL FOUNDRIES

General Description.—In Plate V are shown the plan and elevations of a modern surface-blown converter plant consisting of four converters, each of two tons capacity, mounted on pedestals with roller bearings. Each vessel is under direct and separate control, having fixed to one of its trunnions a worm-wheel geared with motor to give the desired rate of turning. Fig. 98 is a photograph of a modern converter with turning gear, etc., complete. By means of a slip coupling, the motor can be disconnected and the converter operated by a hand-wheel. The electric controllers for the motors are arranged in a small operating house within sight of all the converters, and can be manipulated at will by the man in charge. In cases where electric power is not available, the converters may be operated hydraulically, as shown in Fig. 99. With this arrangement one of the converter trunnions is fitted with a sprocket pinion, over which fits a link chain, the ends of the chain being secured to hydraulic rams.

Arrangement of the Converters.—The converters are connected in pairs by a central blast pipe from the blowers. Between each pair of converters the air enters the trunnions to the blast boxes, and a two-way valve is fitted so that the air is only admitted to one vessel at a time. If the two vessels are in operation during the same day, working alternately for instance, the valve is reversed after each blow. There are three other valves on each blast pipe connecting the converters with the blowers. One is called the non-return flap valve, which prevents the return of explosive gases along the pipe to the blower while the latter is not working, the second is for the admission of air to the converter and is controlled from the operating-house by the man in charge of the plant, while the third is a safety valve for relieving the pressure in the air pipes should any obstruction arise. The second valve referred to may be omitted and the blast controlled from the valve placed in between each pair of converters, but this necessitates a differently constructed valve from the two-way valve referred to above, and the method of operating it is somewhat modified. The blast pipes from each blower to each pair of converters may be coupled together and fitted with suitable stop valves, so that should one of the blowers fail the other could be brought into operation. Further, these pipes may also be coupled to the pipes connecting the cupola blowers with the cupolas with the same object.

Suspended over each converter is a hood with chimney, which passes through the roof of the building in order to carry away the obnoxious fumes during the operation of blowing.

Blowers.—The blowers are independent of each other, and each is directly coupled to a motor through suitable gearing which runs in an oil-bath. Fig. 100

illustrates one of these blowers, which are used for the converters and the cupolas. They are all grouped together in the blower house and are under the control of an attendant, who is in bell communication with the operator of the plant.

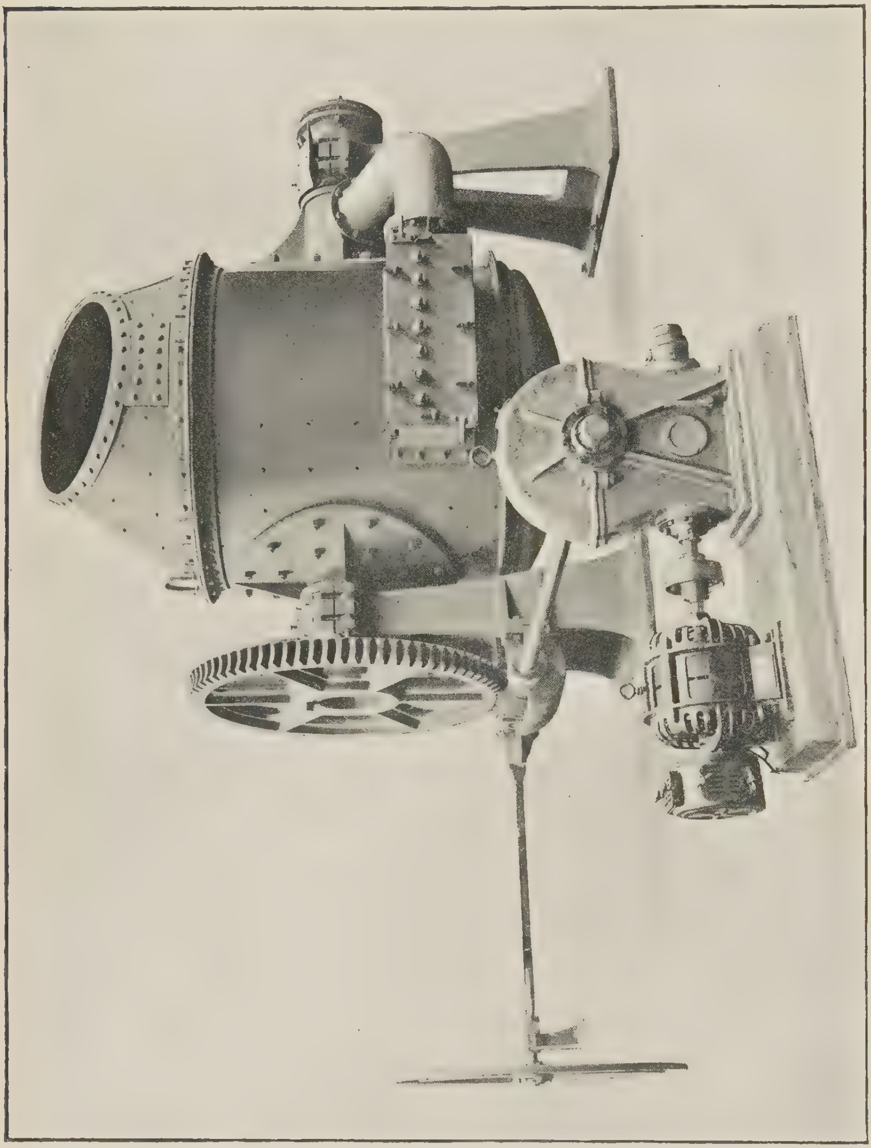


FIG. 98.—Modern Surface-blown Converter arranged for hand and electric tipping. (Made by Messrs. T. Davies & Son, Manchester.)

Pressure gauges for recording the air pressure are fixed in the blower house and in the operating house.

Cupolas.—Raised above the floor-level and arranged in suitable positions upon the staging, are the four cupolas which serve the converters with molten

metal. They are each of special design and of such capacity as to supply a full charge at one tapping. Fig. 101 gives two views of a typical cupola. The pig

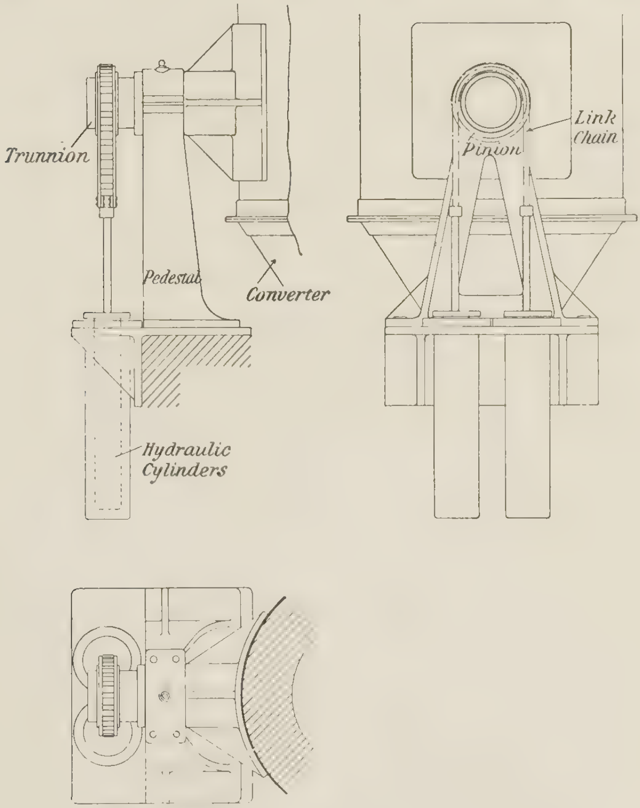


FIG. 99.—Hydraulic Tipping Gear for Small Converters.

iron and scrap, together with the limestone, fluorspar, and coke used in the melting process, are elevated to the charging stage by means of electric lifts

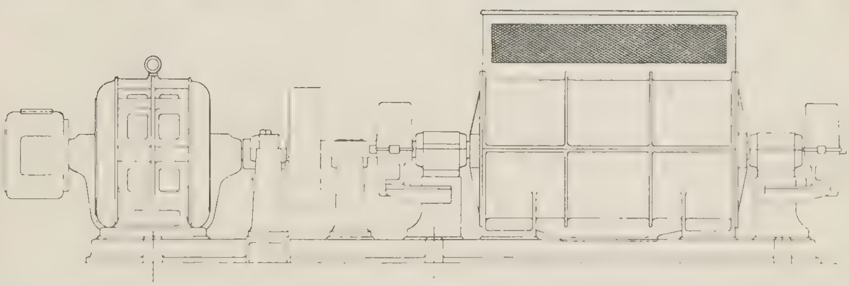


FIG. 100.—High-pressure Motor-driven Roots' Blower for Converter.

which are used for the four cupolas. The iron when melted is tapped into a ladle (which holds a full charge) resting on a weighing-machine and the contents

weighed, after which the ladle is tapped and the metal conveyed by a swinging spout into the converter.

Ladle Pit.—In front of each converter is a ladle pit, at the ends of which a

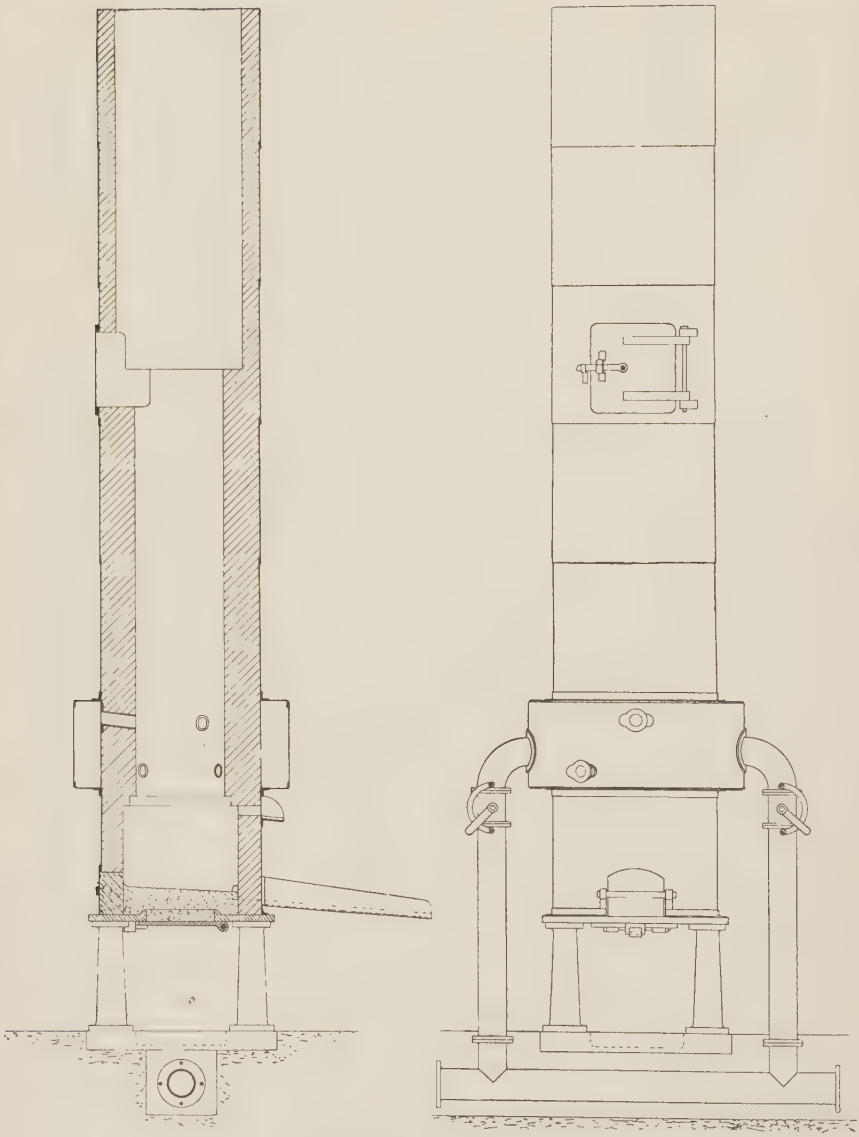


FIG. 101.—Typical Cupola for Melting Converter Charges.

broad-gauge rail track may be laid to admit of a travelling jib crane serving each of the vessels. Overhead cranes are also used in conjunction with the jib travelling crane.

Crucible Furnace and Physic Cupola.—At one side of the Bessemer plant

there is arranged a set of pot holes for melting the alloys used in physicking the steel. A small physic cupola is also employed for melting necessary additions.

Stock Yard.—Behind the Bessemer plant, the pig iron and scrap, together with the coke and other raw materials, are suitably placed to allow of easy removal. From the railway sidings the trucks are taken into the works, bringing the materials alongside the bins and stacks where delivery is required. The handling of the raw materials in the stock yard is therefore reduced to a minimum.

Operation of the Plant

When working the four vessels to their full capacity on the most economical lines, two converters only are in regular operation daily, the 1st and 3rd and the 2nd and 4th, each pair every alternate day. They can, of course, be worked with the 2nd and 3rd vessels blowing at the same time, but the former arrangement is more convenient for pouring and working round the ladle pits. If a heavy casting is being made, say up to 20 tons weight, the four vessels can be used during the same day. While two heats are being blown, charges of molten metal can be tapped into the other two vessels not in operation, so that immediately the first two heats are finished the blast can be turned into the other pair of vessels. This permits of an accumulation of hot steel in a very short time without much "skulling" in the ladles. It is not advisable to run the four vessels in this manner all day long, as they cannot cool sufficiently to admit of their being patched during the night ready for use the next day. The same applies to the cupolas; they are worked most economically when used in alternate pairs, allowing due time for patching.

Weighing Raw Materials.—The raw materials consist of pig iron, scrap, coke, limestone, fluorspar, etc., in their respective proportions, which are placed by the yard men in small tipping waggons, and from thence run to the weigh-bridge in front of each lift. The weight of each kind of material is recorded on the charge sheet before the truck is run on to the lift for elevation to the staging above. Workmen become expert in loading charges quickly, and can judge to within a few pounds what amount to put on the truck for the charge. This saves much adjustment at the weighing machine. One man is made responsible for the accuracy of the charge and for the order in which the different materials are sent to the charging stage.

Melting in the Cupola.—Before the charges are placed in the cupola, the lining is raised to a very high temperature; the lighting up takes place two or three hours before the melted charge is required. After the patching has been done and the bottom made, a wood fire is lighted inside tbe cupola, and coke is added until a deep bed of incandescent coke is formed. When the fettling door and the tap hole have been prepared and closed, the charges are added and the blast turned on. The melt proceeds in the usual manner as in ordinary foundry practice. The regulation of the blast is under the direction of the cupola attendant, who controls the melt according to the requirements of the man who operates the converters.

Weighing the Liquid Iron.—The molten metal is tapped from the cupola into a ladle of special construction lined with firebrick, having a tap hole at the bottom through the side nearest the converters. A spout is attached to the ladle to convey the metal into a swinging spout which serves each pair of converters. An empty ladle rests on a weighing machine opposite each swinging spout

and the weight of the molten charge is recorded before it is tapped into the converter. Fig. 102 shows the arrangement adopted. Before tapping the first charge into the ladle, the latter is heated with a gas or oil jet under air pressure, or with an ordinary wood and coal fire assisted by an air jet.

After the contents of the ladle have been tapped into the converter, the tap hole in the ladle is made good ready for the next charge. After tapping and recording the weight of the first heat each day, the cupola attendant is able to judge, within narrow limits, how much to tap from the cupola into the ladle, without necessarily weighing the contents each time. This is important, as the scouring action of the blast in the cupola enlarges its capacity during a day's melt. The slag line on the ladle is a good guide, and with other indications

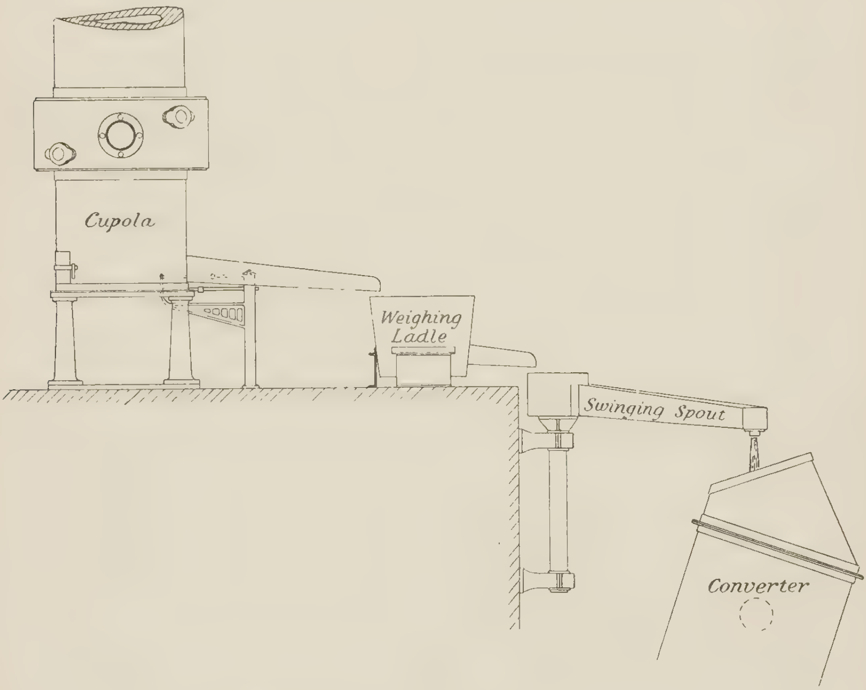


FIG. 102.—Arrangement for running Metal from Cupola to Converter.

which are gained from experience, the attendant can close the tap hole of the cupola immediately he has drawn sufficient.

Preparing the Converter for the Charge.—Silica-bricked vessels are carefully lined with very high grade silica blocks moulded to suit the form of the inside of the converter. The tuyeres are also made of the same material, and are, with the blocks and other bricks, closely jointed together with the best silica cement. When newly lined, the vessel is left to dry a day or two with the blast box open to allow a current of air to pass through to dry the cement. A wood fire is then lighted and the process of heating is proceeded with slowly. The heat is gradually increased with additions of coke, through which a gentle blast of air is passed from the blower until the lining becomes thoroughly heated throughout. Such precaution saves considerable trouble and expense. Liberal allowances are always made for the expansion of the vessel, to prevent

damage. With the lining at a bright red heat the vessel is ready to receive the charge.

With one day's work, the lining may suffer much deformation, making patching more or less a daily necessity. Careful patching prolongs the life of the lining and tuyeres. This is found in most types of furnaces, but it is very remarkable to find some 2-ton vessels producing only 40 heats before a new set of tuyeres is necessary, while others will endure 200 heats. Many things contribute to the durability of linings, not the least being the skill displayed in doing the daily repairs. The converter must, of course, be heated each day before the charge is run into it. It is found that a lining lasts longest when the vessel is used every alternate day, thus allowing due time for cooling and patching.

Setting the Converter when Charged.—The vertical axis of the converter is set at an angle to the vertical when running the metal into the vessel as shown in Fig. 103 *a*, so that the tuyeres are well clear of the molten metal when the full charge is in the converter. To set the vessel in the position suitable for blowing, the plugs in the blast box door are removed and the surface of the metal examined through the plug holes and along the tuyeres. By the help of a small

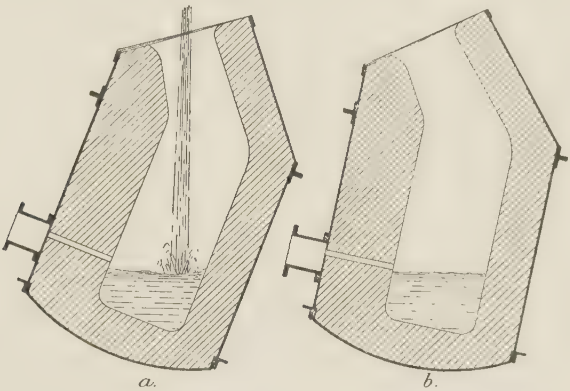


FIG. 103.—*a*. Position of Converter when receiving charge.
b. Position of Converter when ready for blowing. Inclination of tuyeres to horizontal, 10° to 20°.

rod of iron or steel, the exact level and position of the metal is readily ascertained. The converter is gradually brought into position until its vertical axis is from 10 to 20 degrees out of the perpendicular, as shown in Fig. 103 *b*. If the level of the metal in the bath is at the bottom of the tuyere holes when at the inclination stated above, the plugs are replaced in the blast box door and blowing is proceeded with. A chalk mark is sometimes placed on the trunnion and pedestal, or the position may be indicated by means of a pointer and dial, after each charge is "set." The converter can, therefore, be brought round to the same position any time during the operation, when it be found necessary to turn the vessel down.

Progress of the Blow.—The conduct of the blowing operation demands ordinary common sense coupled with a knowledge of what is indicated by the varying colour and length of the flame which issues from the vessel during the oxidation of the principal elements, silicon, manganese and carbon. Practice makes an intelligent operator skilled in observing the reactions which take place.

The first thing aimed at is getting the gases lighted, or what is commonly called the "light." Before this takes place the graphitic carbon in the metal is converted into combined carbon, and some of the iron becomes oxidised and passes

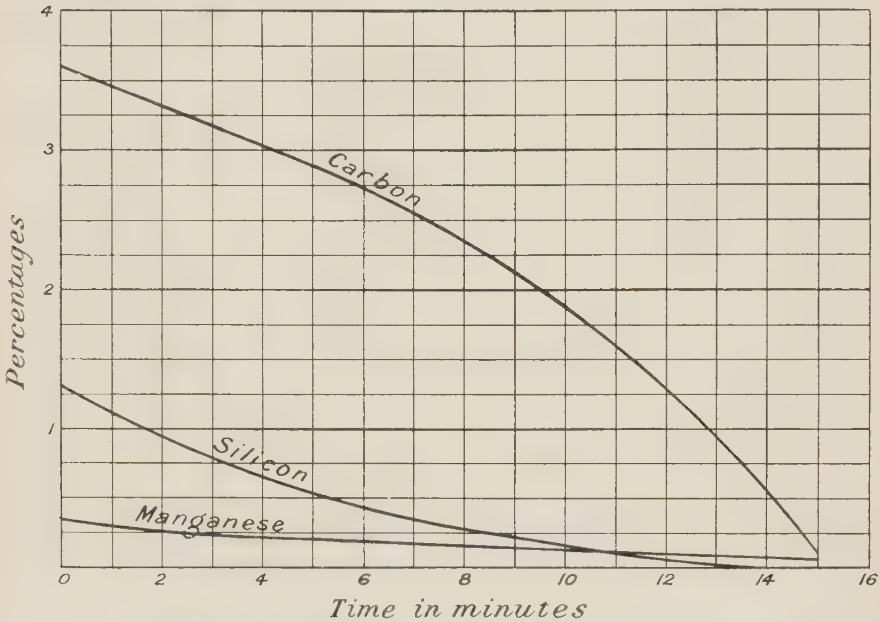


FIG. 104.—Rate of Oxidation of Carbon, Silicon, and Manganese during blow.

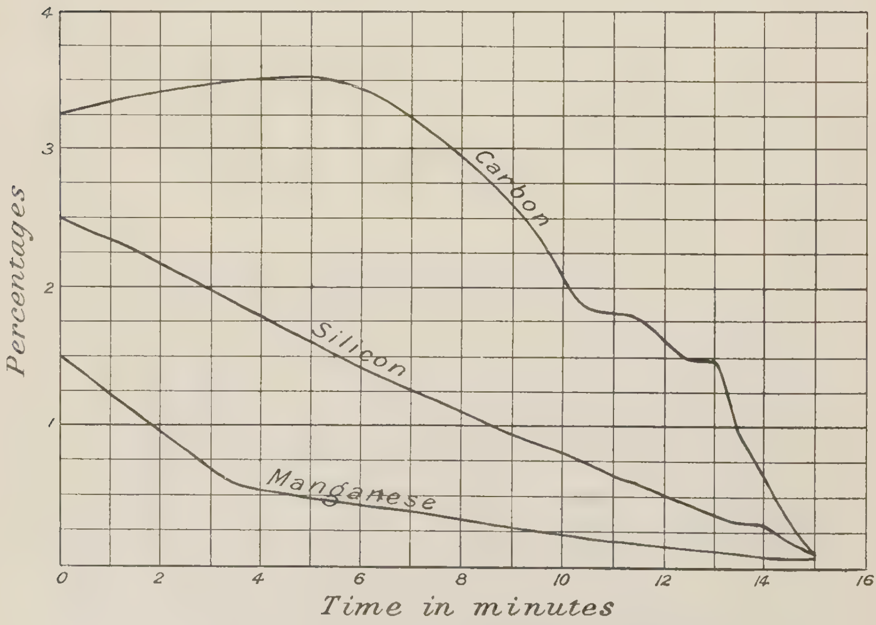


FIG. 105.—Rate of Oxidation of Carbon, Silicon, and Manganese during blow.

off in dense brown fumes. If the metal is very hot it may only take one or two minutes to get the "light" even in the first heat, when the vessel is always at a lower temperature than in subsequent heats, but if the metal is dull it may be several minutes before the gases ignite properly. We have known it to take 30 minutes, but this is a very exceptional case.

The subsequent stages are, as a rule, quite regular; the flame becomes hotter and longer and changes in colour and intensity, showing the passing of the silicon, manganese and carbon. The flame towards the end of the process is so

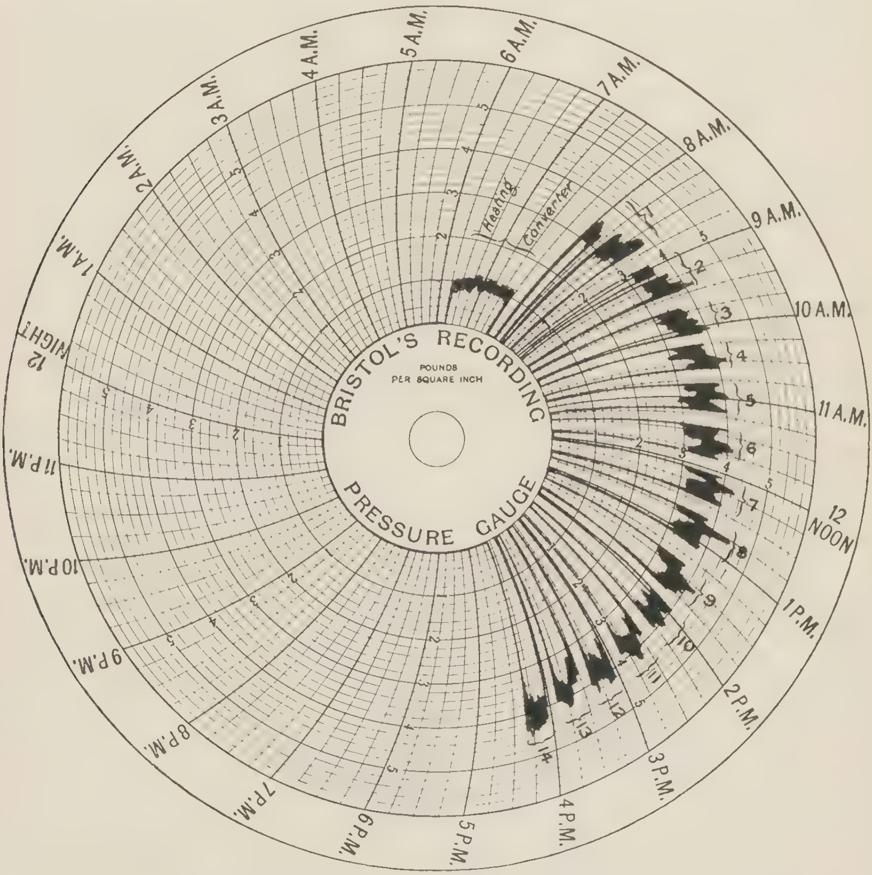
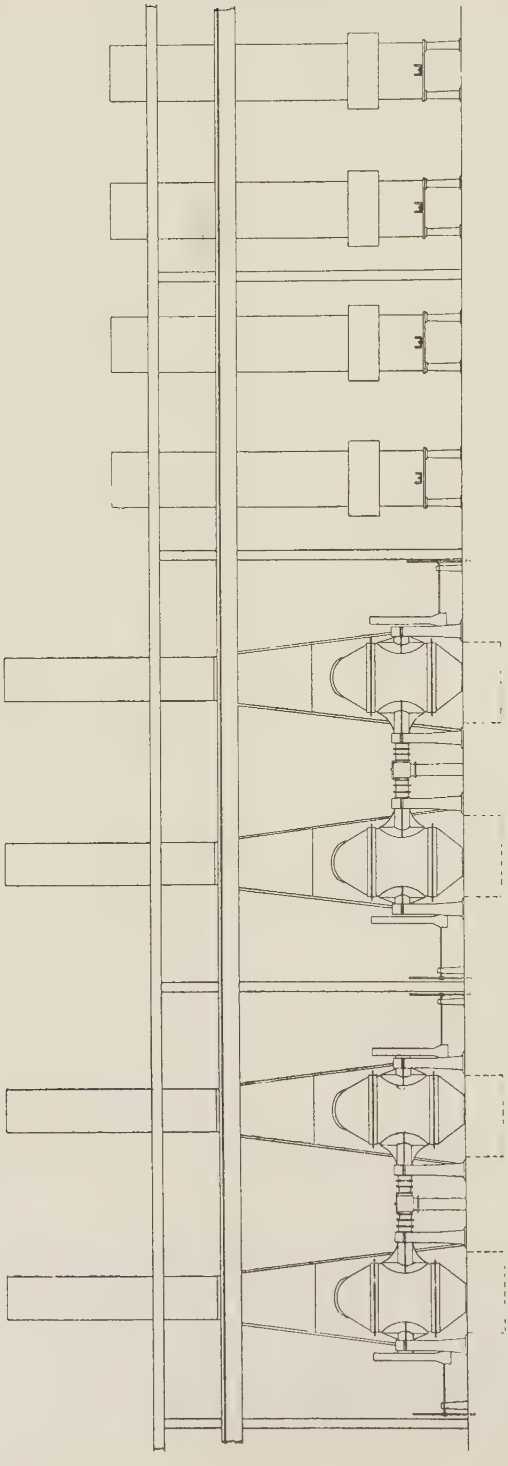


FIG. 106.—Chart for recording Air Pressure during Blow. 14 blows are indicated.

luminous that the naked eye cannot bear to look at it; blue glasses are therefore usually worn during the observation.

When the carbon has been almost completely burned to CO and CO_2, the flame suddenly drops, which indicates at once that the carbon is reduced as much as possible, and the material is now ready to be made into steel of the degree of quality desired, as far as additions of carbon, silicon, manganese and other alloys will do this. Figs. 104 and 105 show curves of the time taken to eliminate the various constituents from the metal. These indicate rapid blows for surface-blown plants.



Front Elevation.

Fig. 107.

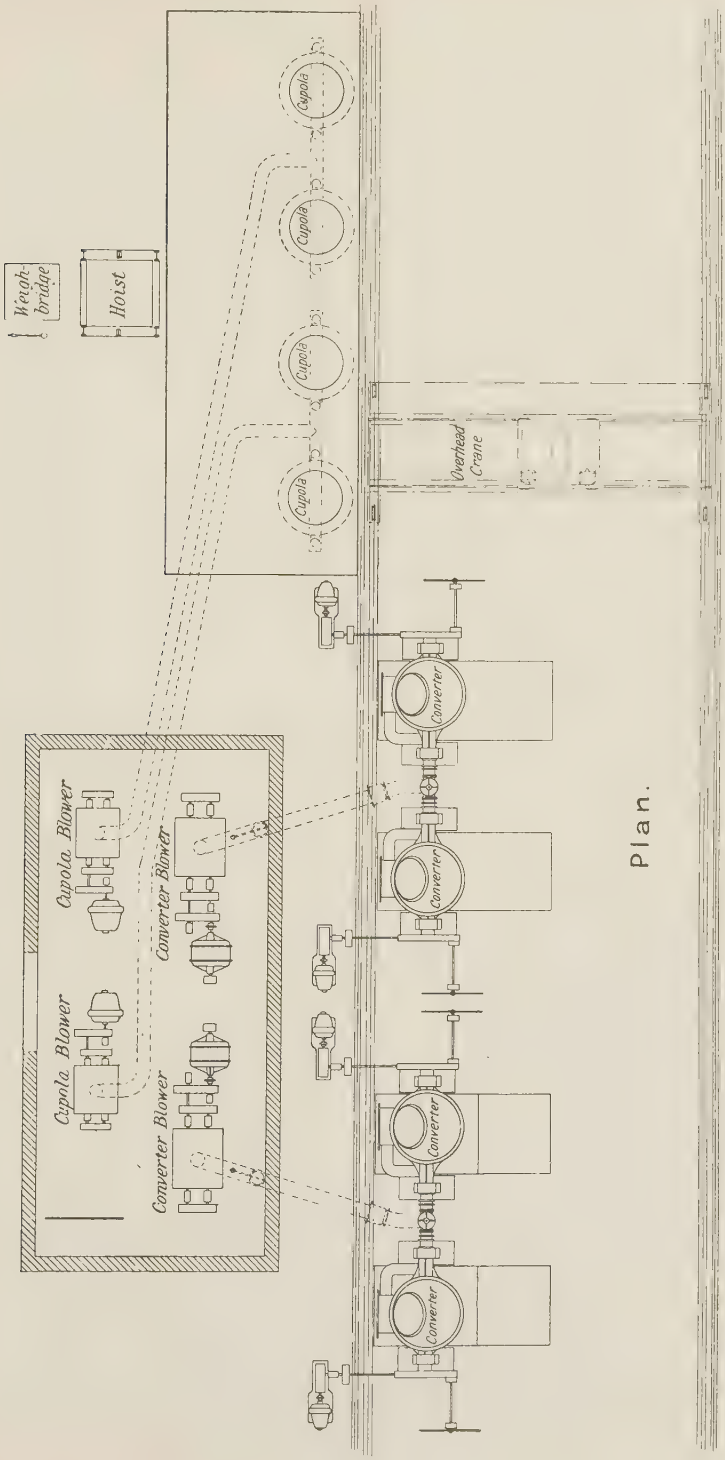


FIG. 107.—Arrangement of Four 2-ton Surface-blown Converter Plant with Cupolas on Floor-level.

Duration of the Blow.—The time taken to convert a 2-ton charge of hot metal into steel varies considerably according to certain conditions, which include among others :—

1. The richness of the pig iron and scrap mixture in carbon, silicon and manganese.
2. The temperature of the molten metal at the commencement of the blow.

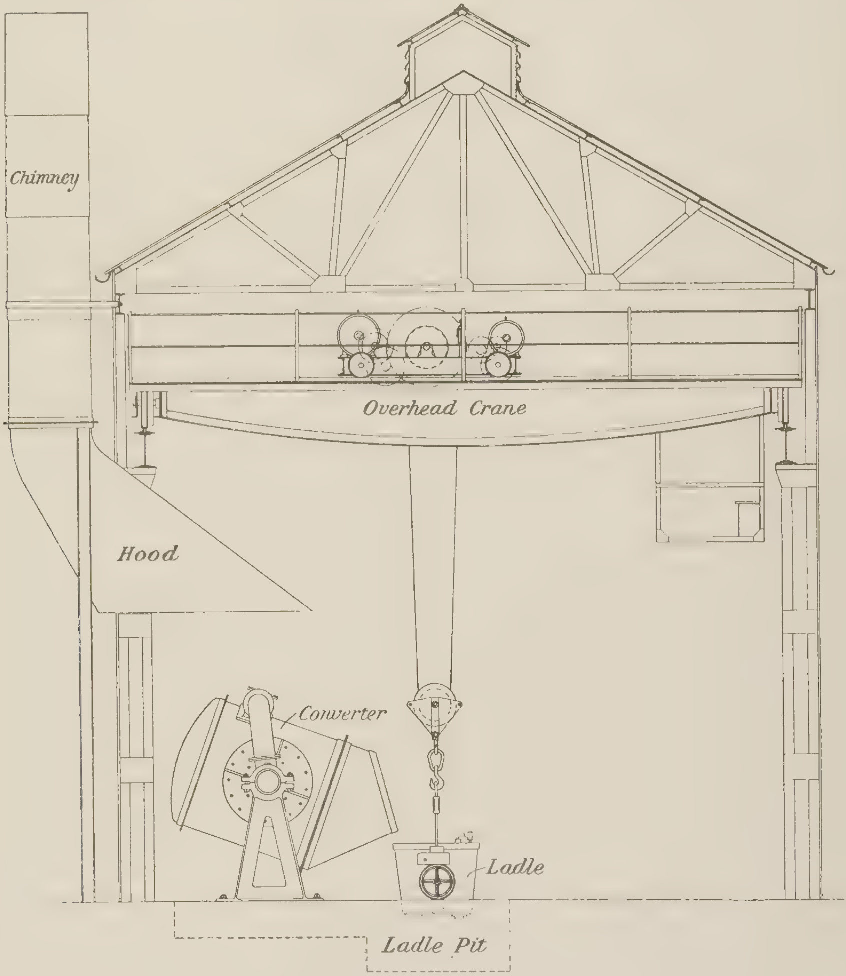


FIG. 108.—2-ton Converter Plant. Ladle in position to receive finished charge.

3. The condition of the lining of vessel and tuyeres.
4. The regulation of the blast pressure.
5. The skill of the operator.

The time and pressure are automatically recorded on charts which show a day's heats. This is most useful for checking one heat with another. Fig. 106 shows the chart commonly used, and gives the progress of heats. The recording instrument and pressure gauge are placed on the wall of the room, where the operating valves and controllers are all within reach and under the direction of

the man in charge of the blowing. The time taken to complete a blow varies from 15 to 40 minutes, and may be even longer if the tuyeres are troublesome during the operation.

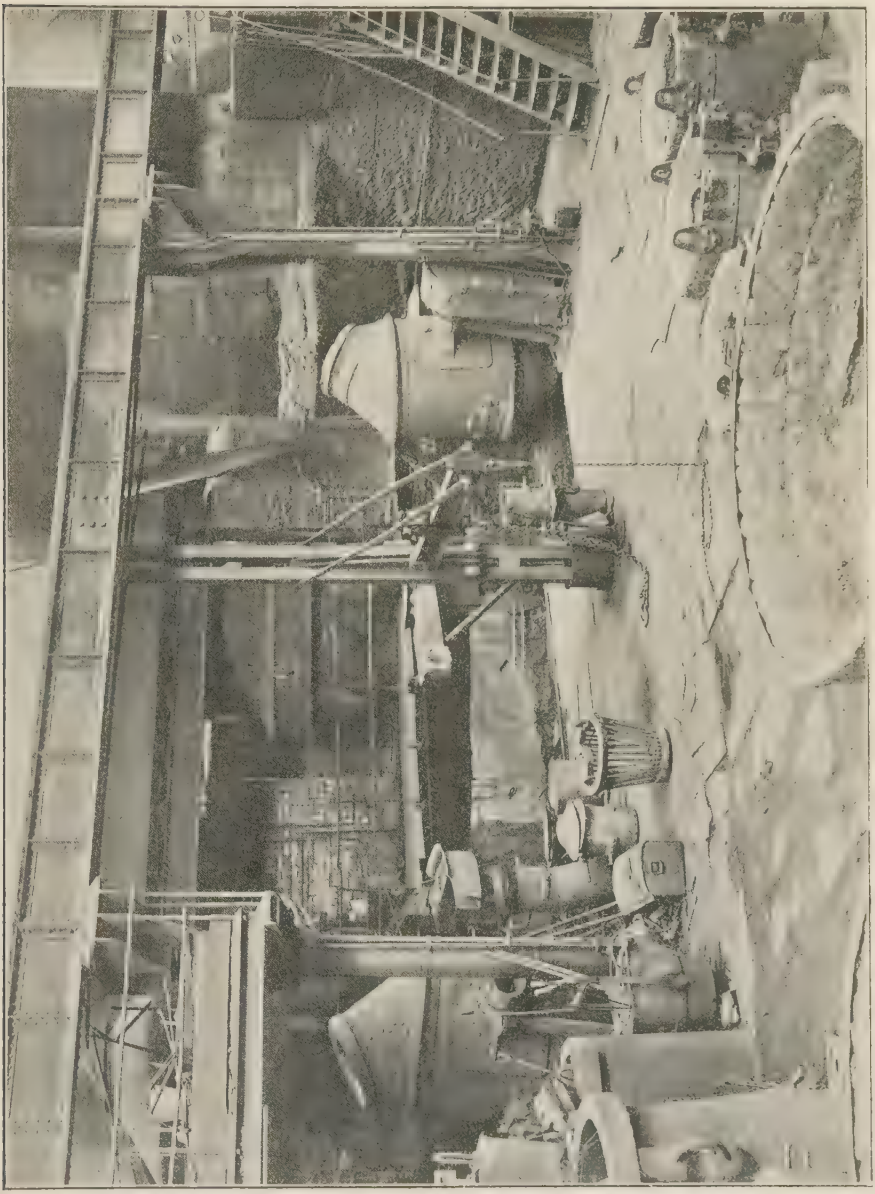


FIG. 109.—Two 2-ton Surface-blown Tropenas Converter Plant at the Lancashire and Yorkshire Railway Works, Horwich.

Physicking the Charge.—The final additions to the charge are either added in the liquid state entirely, or partly in the liquid and solid states, or at other times entirely in the solid form after being heated to redness. If special steels

are made from the blown metal, the ferro-alloys are usually melted in crucibles and poured from them into the ladle waiting to receive the charge from the converter vessel. The cupola is sometimes used for melting these "finals," and serves the purpose quite satisfactorily when pig iron for recarburising is required, but for melting the ferro-alloys the oxidation losses do not warrant its use in the ordinary form.

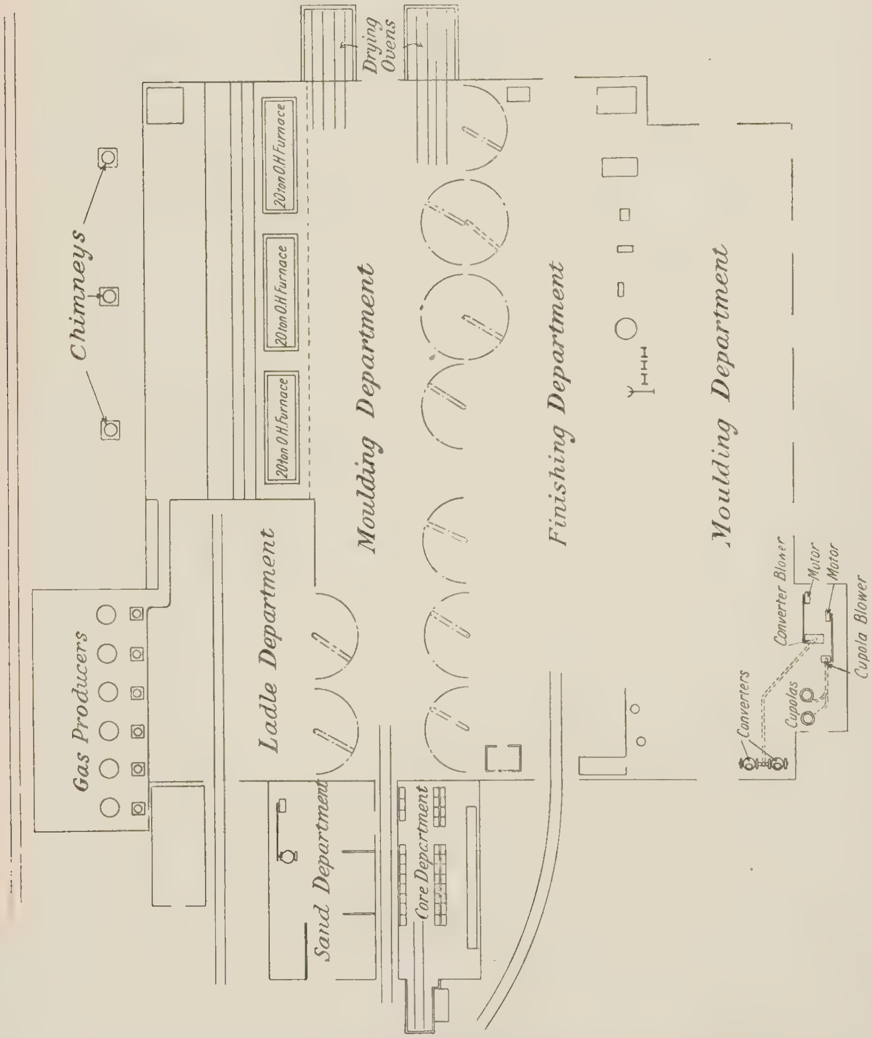


FIG. 110.—Plan of Part of the Scullin-Gallagher Iron and Steel Co.'s Steel Foundry, St. Louis, U.S.A., showing Converter Plant.

It is not an uncommon practice to recarburise the charge when mild steel is required by throwing lumps of cold pig iron, previously dipped in water, into the bath of liquid steel. This practice is usually accompanied by a loud report and the ejection of slag from the converter.

After physicking the charge with solids, a mixing bar is used to stir the material. The converter vessel is also rocked up and down with the same object.

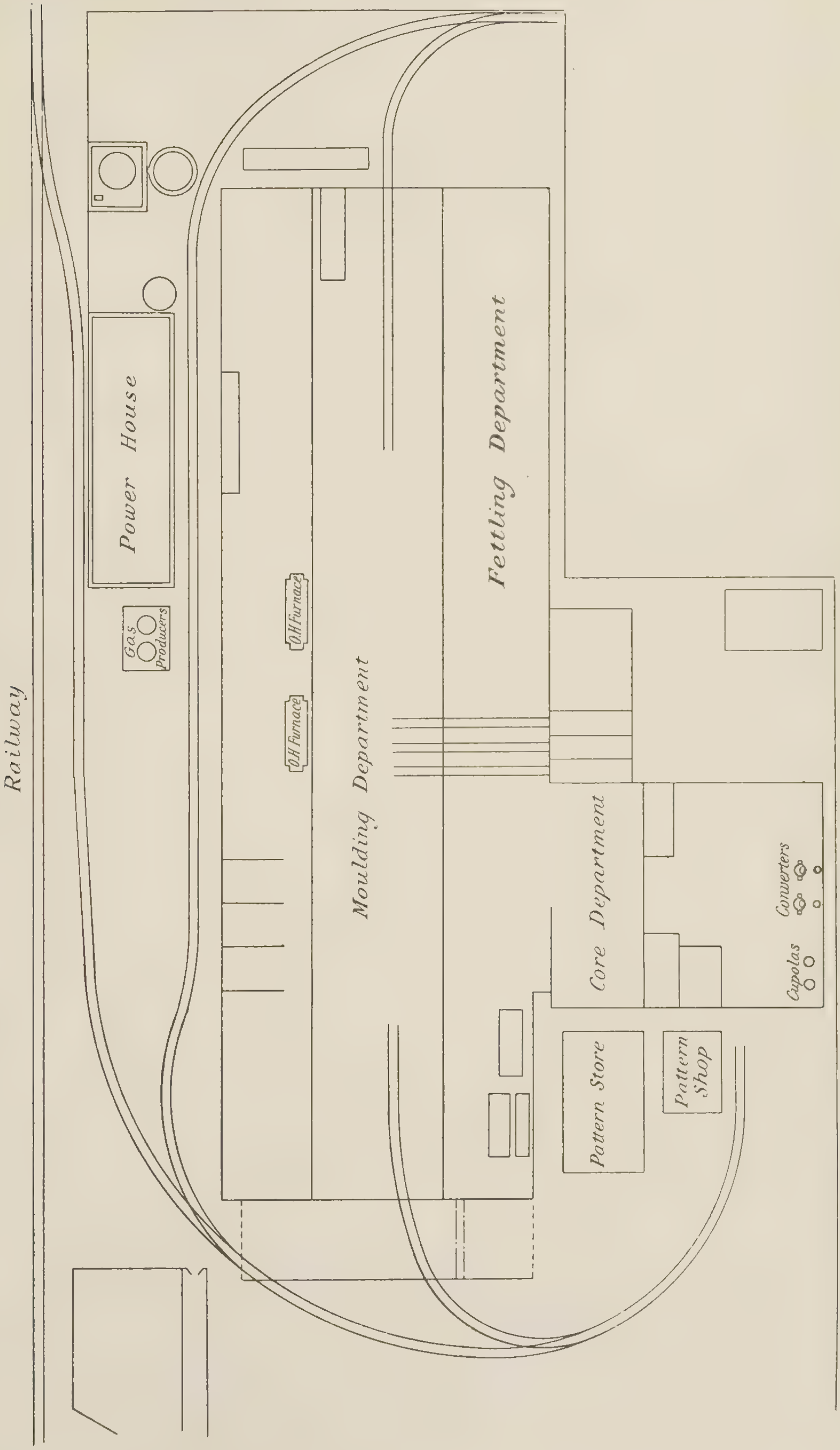


FIG. 111.—Plan of Steel Foundry (showing Converter Plant), Detroit Steel Casting Co., U.S.A.

Pouring.—The pouring is controlled from the operating house by the "blower," who can see the converter and ladle while regulating the rate of flow of the steel. When the whole charge is taken into one ladle, the latter is suspended from a Denison or other suspended weighing machine which hangs from the overhead or travelling jib crane. The weight is taken before and after pouring the steel into the ladle, and the amount recorded.

When the charge is poured from the converter in small ladles or shanks, the electric motor is uncoupled and the hand turning gear brought into operation. A nose brick is placed in the mouth of the converter and held there by a suitable strap in front of it, secured by two brackets fixed to the platework of the vessel.

Cranes.—The overhead cranes are of ample power to lift ladles with several charges of steel. The jib crane is most useful in clearing the pits quickly of slag from the cupolas and converters, the slag from the former running direct into pans on trucks, while from the converters it falls into the ladle pits. For transferring ladles of steel from one vessel to another in different bays, the jib crane is indispensable.

Other Arrangements of Converter Plants.—In Fig. 107 is illustrated an arrangement of converters and cupolas placed on the floor-level, it being sometimes more convenient to operate the cupolas in this position than when raised upon staging. The metal is transferred from the cupolas to the converters in a ladle carried by overhead crane. The same crane is used for taking the finished charge from the converter. Fig. 108 shows ladle suspended from crane ready to receive the charge.

In Fig. 109 is shown photograph of the two 2-ton converter plant at the Lancashire and Yorkshire Railway Works, Horwich. Both converters face each other and are served by cupolas from which the hot metal is run direct into the converters.

The general arrangement of the 3-ton converter plant shown in Fig. 110 is that of the Scullin-Gallagher Iron & Steel Co., St. Louis, U.S.A. It will be observed that the cupolas are placed at right angles to the converters.

In Fig. 111, showing a plan of the foundry of the Detroit Steel Casting Co., Detroit, U.S.A., is given the position of the converters in relation to the cupolas.

CHAPTER XXI

COST OF STEEL PRODUCED IN SURFACE-BLOWN CONVERTER PLANTS FOR STEEL FOUNDRIES

2-TON CONVERTER PLANT WITH FOUR CONVERTERS

Output and Cost of Plant.—The cost of steel produced by the 2-ton converter plant with 4 converters, described and illustrated in the previous chapter, is calculated on the basis of the continuous use of two converters per day with an output of 56 tons of steel, that is, each converter "blowing" 14 heats per day of 10 hours. The liquid steel produced can be used for castings from a few lbs. weight up to 20 tons each, the plant already described being of ample proportions to give these results.

The cost of plant including the following items is approximately £10,000, varying according to the conditions of site and the alterations necessary to existing buildings.

The items are as follows:—

Four 2-ton converters, mounted on pedestals with roller bearings, each arranged with tipping gear operated by electric motor and with hand-turning gear, together with the necessary electric controllers and switches.

Four cupolas, each provided with the latest equipment for rapid melting and specially designed to melt and hold the complete charge at a high temperature; complete with blast valves and pressure gauges.

Two high-pressure Roots' blowers, built on separate foundations, each coupled direct to an electric motor bolted to an extension of the bedplate of the blower. Each blower to supply the necessary blast to the converters through cast-iron pipes and valves coupled to them. Pressure gauges, operating valves, and electrical equipment included.

Two low-pressure Roots' blowers with motors, arranged in the same manner as the high-pressure blowers and motors above, but to supply the blast required in the cupolas. Alternatively, motor-driven fans may be installed.

One electrically driven lift with motor and gearing, controllers, etc., complete.

One weighbridge, with the latest improvements, for weighing the materials.

One weighing machine for weighing charge from cupolas.

One ladle and carriage, with motor and gear for operating them to and from the cupolas, weighbridge, and converters.

One high-speed jib crane for operating in front of the ladle pits.

Two overhead cranes for serving the foundry with molten steel from the converters.

All structural steelwork, including stagings for cupolas and suitable roofing.

Four hoods and chimneys for converters.

One coke-fired crucible melting furnace with three 4-pot melting holes for melting additions to charge.

One small cupola for melting additions, with the necessary pipe connections from the blast mains of the larger cupolas.

One small furnace for heating ferro-alloys when added to charge in the solid state.

One set of ladles, including two 12-ton ladles and six 3-ton ladles.

Blower house with the necessary switchboard equipment for the complete plant.

All wiring, switches, starters, and electrical accessories complete.

All blast pipes, spouts, chutes, slag and coke pans, tipping trucks, tools, etc.

All brickwork, concrete foundations, pits, linings for converters, cupolas, and ladles.

The whole plant erected complete and set to work.

It is assumed that the power is supplied to the switchboard from an outside source, the cost of plant for which is not included in the above figures.

It will be obvious that while the overhead cranes are an absolute necessity in handling the steel produced from the converters, their cost should not be entirely charged to steel making. During one full day's work, the cranes would be employed about half their time in serving the steel plant, and the other half in the foundry. Half their value only is therefore added to the cost of the steel plant.

Allowing a depreciation of 10 per cent. on the complete steel plant, 5 per cent. on the buildings, and $2\frac{1}{2}$ per cent. on the foundations, the annual charge for depreciation is :—

	£
£7000 @ 10 %	700
£1000 @ 5 %	50
£2000 @ $2\frac{1}{2}$ %	50
Total . .	£800

The output of the plant, if worked 47 full weeks per year = 320 × 47 = 15,040 tons per annum. Say 15,000 tons.

$\therefore$ Charge for depreciation per ton of liquid steel $= \frac{800 \times 20}{15,000} =$ 1*s*. 1*d*.

Interest on £10,000 at 5 per cent. = £500.

$\therefore$ Charge for interest per ton of liquid steel $= \frac{500 \times 20}{15,000} =$ 8*d*.

$\therefore$ Total charge for depreciation and interest per ton of liquid steel = 1*s*. 9*d*.

Working Costs (per Ton of Liquid Steel for Carbon Steel Castings)

Cost of Repairs and Stores.—The repairs include all materials and labour expended in patching converters, cupolas, ladles, chutes, and furnaces daily ; the periodic relining of the converters, cupolas, and ladles with brickwork ; all repairs to the mechanical and electrical parts of the plant necessary to maintain them in working condition ; and all hand tools used about the plant. The stores include oil, grease, waste, asbestos, gloves, brushes, and all miscellaneous items required.

The average cost of repairs and stores taken over a period of 12 months, including the cost of relining converters, etc., is 4*s*. per ton of liquid steel.

Cost of Fuel.—The fuel includes coke used in heating cupolas, converters, and crucible furnace, as well as the fuel actually used in melting. The average

weight of coke used per ton of liquid steel produced is $3\frac{1}{2}$ cwts., and taking the price of coke at £1 2*s.* 6*d.* per ton, the cost of fuel per ton of liquid steel = 3*s.* $11\frac{1}{2}$*d.* A small amount of fuel is also required for heating the ferro-alloys when added to the converters in the solid state. This amounts to a fraction of a penny per ton of steel.

Cost of Labour.—The labour includes all men required to work the plant, exclusive of those referred to under the heading "repairs" already dealt with. The men required are:—

Four converter men.
Two cupola attendants.
Two " chargers.
Eight " charge wheelers.
One man in charge of blowers and other plant.
One man in charge of physic cupola.
Two men at crucible furnace.
Five men patching, repairing, and operating ladles.
One man at jib crane and part wages of two men on overhead cranes.
One foreman "blower."

Total wages for one week	£55
Steel produced in ladle during one week . .	320 tons.

$$\therefore \text{ Cost per ton of liquid steel } = \frac{55 \times 20}{320} = 3s.\ 5\tfrac{1}{2}d.$$

Adding 50 per cent. as part expenses of chemist and management = 1*s.* 9*d.* per ton.

The total cost of labour per ton of liquid steel = 5*s.* $2\frac{1}{2}$*d.*

Cost of Power.—The cost of power includes all electrical power used in operating the blowers for converters and cupolas, for tipping the converters, operating the lift, and half the power consumed by the two overhead electric cranes. It also includes the fuel and water used by the steam jib crane.

Assuming the cost of current at the switchboard to be $\frac{1}{2}$*d.* per unit, the cost is as follows:—

	s.	*d.*	
Current for week, 8960 units = 28 units per ton of steel, which at $\frac{1}{2}$*d.* unit . . . . =	1	2	per ton.
Fuel and water for crane . . . . =	0	1	"
∴ Cost of power per ton of liquid steel =	1	3	"

Cost of Raw Materials.—The weights and cost of raw materials used in one week to produce 320 tons of liquid steel are given below:—

Materials used for Actual Manufacture (excluding Physics)

	T.	C.	Q.	Lbs.		£	*s.*	*d.*
Pig	147	12	0	0	@ 65*s.* 0*d.* ton .	479	14	0
Scrap . . .	192	12	0	0	@ 55*s.* 0*d.* " .	529	13	0
Limestone . .	14	14	0	0	@ 4*s.* 2*d.* " .	3	1	3
Fluorspar . .	3	6	0	0	@ 16*s.* 0*d.* " .	2	12	10
Ferro-silicon .	3	12	0	0	@ 85*s.* 0*d.* " .	15	6	0
					Total	£1030	7	1

Physic Materials

	T.	C.	Q.	Lbs.			£	s.	d.
Pig	17	13	0	0	@ 65s. 0d.	ton	57	7	3
Scrap	10	18	0	0	@ 55s. 0d.	,,	29	19	6
Ferro-manganese	2	15	2	0	@ 8s. 6d.	cwt.	23	11	9
Ferro-silicon	2	6	3	0	@ 11s. 8d.	,,	27	5	5
Aluminium	0	2	3	3	@ 0s. 7d.	lb.	9	1	5
Fluorspar	0	7	1	14	@ 16s. 0d.	ton	0	5	11
					Total		£147	11	3

Cost of raw material per ton of liquid steel in ladle

$$= \frac{£1177\ 18s.\ 4d.}{320} = £3\ 13s.\ 8d.$$

Summary of Costs

Cost of plant, £10,000.

	£	s.	d.
Depreciation and interest	0	1	9
Repairs and stores	0	4	0
Fuel	0	3	11½
Labour + 50 per cent. for management	0	5	2½
Power	0	1	3
Raw materials	3	13	8
Total cost per ton of liquid steel	£4	9	10

Loss of Raw Material.—The combined loss in the process of melting and blowing varies from 15 to 20 per cent. of the material charged. The kind of scrap melted with the pig iron plays an important part in the loss. The best results are obtained when heavy, clean scrap is used.

2-Ton Converter Plant with Two Converters

The 2-ton converter plant shown in Fig. 112 (pp. 220–21) is generally in accordance with Plate V, but half the size.

Output and Cost of Plant.—The output from this plant is based on 14 heats per day of 10 hours, the average heat weighing 2 tons in the ladle. One converter is worked daily, producing 28 tons of liquid steel. The steel can be used for castings varying in weight from a few lbs. to 7 tons each.

The cost of plant, including the following items, is approximately £6000.

Two 2-ton converters.
Two cupolas.
One high-pressure blower.
One low-pressure blower or fan.
One electric hoist.
One weighbridge for weighing raw materials.
One weighing machine for weighing molten metal.
One ladle for weighing machine.
One high-speed steam jib crane.
One overhead electric crane.

All structural steelwork, including staging and roofing for cupolas.
Two hoods and chimneys for converters.
One coke-fired crucible melting furnace, with three 2-pot holes.
One small physic cupola.
One small heating furnace.
One 10-ton and four 3-ton ladles.
One blower house.
All electrical and mechanical equipment complete.
All blast pipes, spouts, chutes, etc.
All foundations, brickwork, etc., complete.
The whole plant erected and set to work.

The explanatory remarks regarding the items of plant for the 2-ton converter plant with 4 converters described in the first part of this chapter apply to the same parts of the plant enumerated above.

Annual charge for depreciation on plant:—

Complete steel plant, except buildings,	£4500 @ 10 %	=	£450
Buildings	£ 500 @ 5 %	=	25
Foundations, etc.	£1000 @ $2\frac{1}{2}$ %	=	25
Annual charge for depreciation . .			£500

Interest on capital outlay, £6000 @ 5 % . = £300
∴ Annual charge for depreciation and interest = £800

The output of liquid steel per year = 7500 tons, *i.e.* half the output of the 2-ton converter plant with 4 converters.

∴ Total charge for depreciation and interest per ton of liquid steel

$$= \frac{800 \times 20}{7500} = 2s.\ 1\tfrac{1}{2}d.$$

Working Costs (per Ton of Liquid Steel for Carbon Steel Castings)

Cost of Repairs and Stores.—All the items referred to under the same heading for the 2-ton converter plant with 4 converters are included in this cost, and all prices for materials and stores are taken on the same basis.

Average cost of material, labour, and stores per ton of liquid steel = 4*s.* 6*d.*

Cost of Fuel.—The average weight of coke consumed is 4 cwts. per ton of steel in the ladle; this is increased as compared with the same item in the foregoing cost, on account of the crucible furnace and physic cupola, which do not yield so much per day as when used in conjunction with the 2-ton converter plant with 4 converters, and consequently more fuel is used. The heating-up of both furnaces has to be done, whether the output is great or small. Taking the price of coke at £1 2*s.* 6*d.* per ton, as before, the cost of fuel per ton of liquid steel is 4*s.* 6*d.*

Cost of Labour.—The men employed are as follows:—

Two converter men.
One cupola attendant.
One cupola charger.
Four cupola charge wheelers.
One man in charge of blowers and other plant.
One man in charge of physic cupola.
One man at crucible furnace.

Three men patching, repairing, and operating ladles.
One man at jib crane and part wages of man on overhead crane.
One foreman "blower."

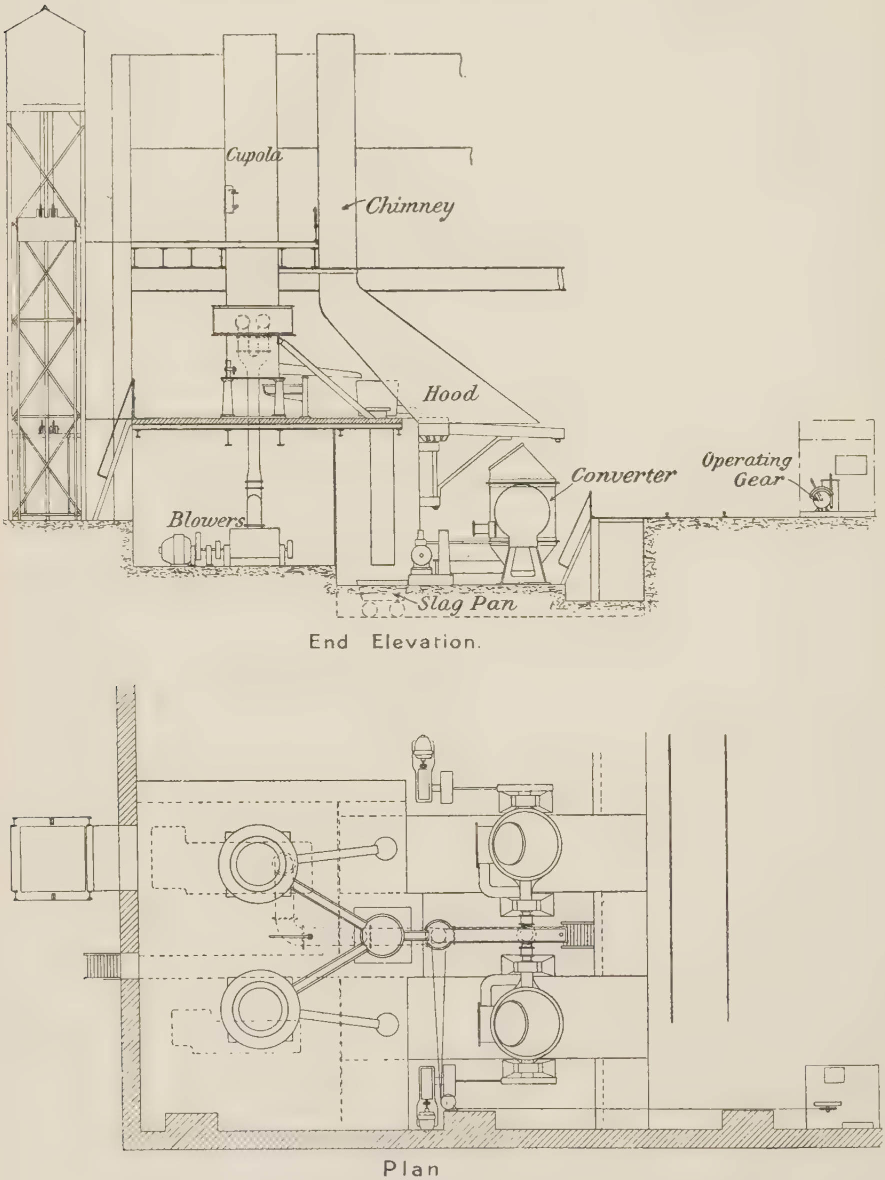


FIG. 112.—General Arrangement of Two 2-ton Surface-blown Converter Plant.

Total wages for one week	£35
Steel produced in ladle in one week	160 tons.

$$\text{Cost per ton of steel} = \frac{35 \times 20}{160} = 4s.\ 4\tfrac{1}{2}d.$$

Adding 50 per cent. as part expenses of chemist and management = 2*s.* 2½*d.* per ton. The total cost of labour per ton of liquid steel = 6*s.* 7*d.*

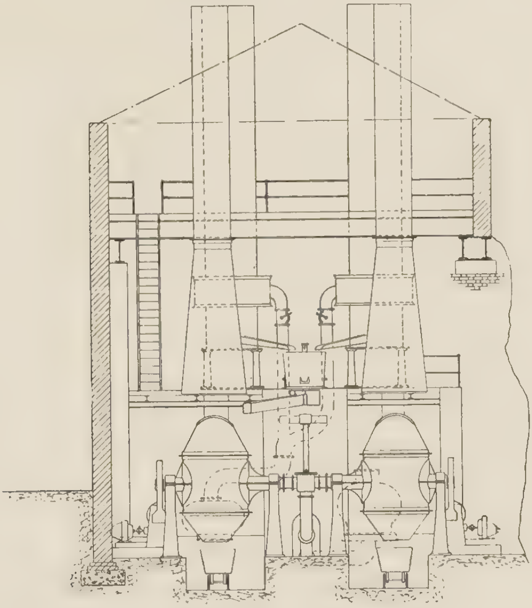


FIG. 112.

Cost of Power.—Assuming the cost of current at the switchboard to be ½*d.* per unit, the cost of power is as follows:—

Current consumed per week, including overhead electric crane = 4480 units = 28 units per ton of steel.

	s.	*d.*	
28 units @ ½*d.* unit	1	2	per ton.
Fuel and water for crane	0	1½	,,
∴ Cost of power per ton of liquid steel =	1	3½	

Cost of Raw Materials.—Using the same proportions of raw materials as given on p. 217, and adopting the same prices, the total cost of raw materials used in producing 160 tons of liquid steel = £588 19*s.* 2*d.*

∴ Cost of raw materials per ton of liquid steel in ladle = £3 13*s.* 8*d.*

Summary of Costs

Cost of plant, £6000.

	£	s.	d.
Depreciation and interest	0	2	1½
Repairs and stores	0	4	6
Fuel	0	4	6
Labour + 50 % for management	0	6	7
Power	0	1	3½
Raw materials	3	13	8
Total cost per ton of liquid steel	£4	12	8

2-Ton Converter Plant with One Converter.

In comparing the one 2-ton converter plant shown in Fig. 113 with the plant illustrated in Fig. 112, the general features in the design remain the same, and equal accuracy is observed in the construction and working of the details of the plant. There are, of course, other designs of plants (some of which are described later) used in foundries where it is not considered necessary to weigh the molten metal from the cupola, and where it is found convenient to have the cupola on the same floor-level as the converter.

Output and Cost of Plant.—The capacity of the plant enumerated below is based on the same output per converter as the two plants previously described, namely, 14 heats per day of 10 hours, each heat having an average weight of 2 tons. As one converter only is used, it is in operation but 3 days per week, every alternative day being employed in patching and repairing the lining. The weekly output of liquid steel amounts to 84 tons, and can be used for castings weighing from a few lbs. to 4 tons each.

The approximate cost of plant shown in Fig. 113, including the following items, is £3500.

One 2-ton converter.
One cupola.
One high-pressure blower.
One low-pressure blower or fan.
One electric hoist.
One weighbridge for weighing raw materials.
One weighing machine for weighing molten metal.
One ladle for weighing machine.
One high-speed jib crane.
One overhead electric crane.
All structural steelwork, including staging and roofing for cupolas.
One hood and chimney for converter.
One crucible coke-fired melting furnace, with three 2-pot holes.
One small physic cupola.
One small heating furnace.
One 6-ton and three 3-ton ladles.
One blower house.
All electrical and mechanical equipment complete.
All blast pipes, spouts, chutes, etc.
All foundations, brickwork, etc., complete.
The whole plant erected and set to work.

Although one converter only is used, the items of plant are the same size as

in the 2-ton converter plant with 4 converters, except in the case of the overhead electric travelling crane, which is made lighter, to suit the load. No generating plant is included, it being assumed that the electric current is supplied to the switchboard from an outside source.

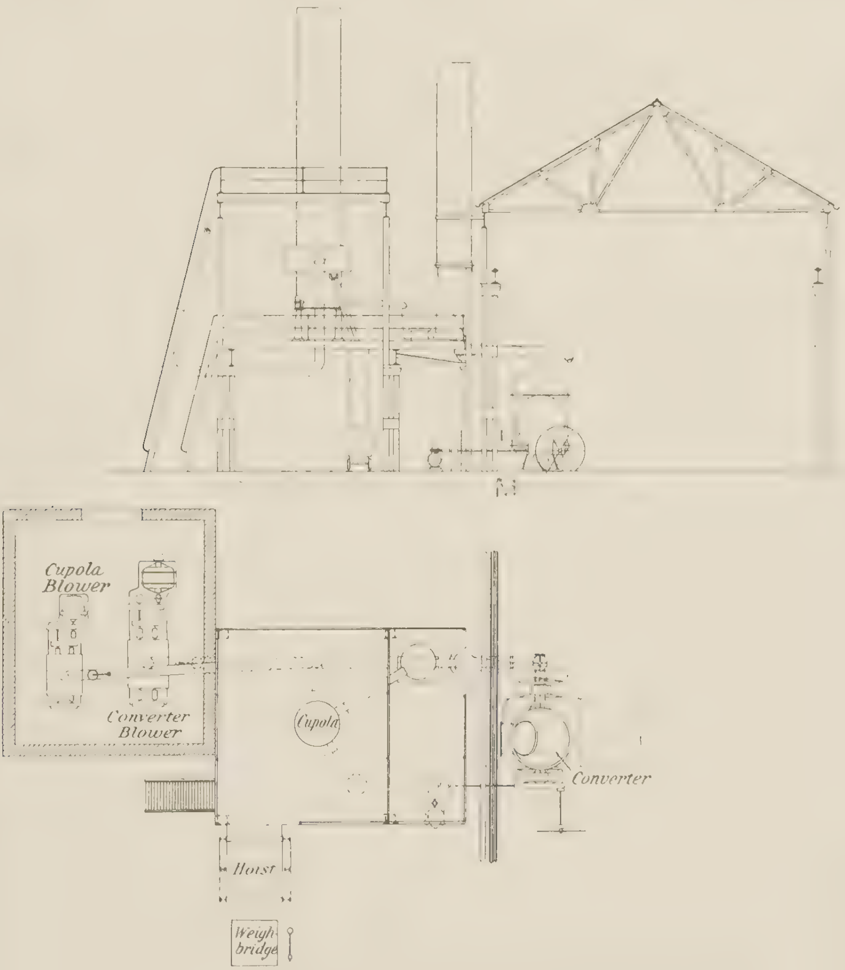


FIG. 113.—Arrangement of One 2-ton Surface-blown Converter Plant.

Annual charge for depreciation on plant :—

			£	s.	d.
Complete steel plant, except buildings,	£2500 @ 10 %	=	250	0	0
Buildings	£ 300 @ 5 %	=	15	0	0
Foundations, etc.	£ 700 @ $2\frac{1}{2}$ %	=	17	10	0
Annual charge for depreciation			£282	10	0

Interest on capital outlay, £3500 @ 5 % = £175 0s.
∴ Annual charge for depreciation and interest = £457 10s.

The output of liquid steel per year = 84 (tons per week) × 48 (working weeks) = 4032 tons.

∴ Total charge for depreciation and interest per ton of liquid steel

$$= \frac{£457\ 10s.}{4032} = 2s.\ 3\tfrac{1}{2}d.$$

Working Costs (per Ton of Liquid Steel for Carbon Steel Castings)

Cost of Repairs and Stores.—The same items are included in these costs as in the larger plants previously considered. The prices of the materials are also taken at the same figures.

Average cost of materials, labour, and stores per ton of liquid steel = 5*s.*

Cost of Fuel.—The consumption of coke per ton is about the same as in the 2-ton converter plant with 2 converters, namely, 4 cwts., and at a price of £1 2*s.* 6*d.* per ton the cost of fuel per ton of liquid steel = 4*s.* 6*d.*

Cost of Labour.—The men employed are as follows:—

Two converter men.
One cupola attendant.
One „ charger.
Three „ charge wheelers.
One man in charge of blowers and other plant.
One man in charge of physic cupola.
One man at crucible furnace.
Two men patching, repairing, and operating ladles.
One man at jib crane, and part wages of man on overhead crane.
One foreman "blower."

It will be observed that the same number of men are employed for 3 days of the week while the converter is in operation, as in the case of the double plant, with the exception of the cupola charge wheelers and the ladle men. The reduction in the number of charge wheelers is made possible by their being able to get several charges upon the cupola stage during the days when the repairs are effected. The ladle men are also reduced in number, because they have more time available for repairs when the plant is not in operation.

Intermittent working of plant always increases the labour bill. Instead of patching and repairing the converter and cupola during the night, as in the case of the double and larger plants, this is done during the day by the converter and cupola men. The remainder of the men are found general labouring work in the foundry, but the duties are not regular, and it often amounts to a highly paid labourer being employed on a class of work of a lower value.

Wages per week charged to steel plant	£21
Steel produced in one week	84 tons.

$$\text{Cost per ton of steel} = \frac{21 \times 20}{84} = 5s.$$

Adding 50% as part expenses of chemist and management = 2*s.* 6*d.* per ton.

The total cost of labour per ton of liquid steel = 7*s.* 6*d.*

Cost of Power.—Assuming the cost of current at the switchboard at ½*d.*[1] per B.O.T. unit as before, the cost of power is as follows:—

[1] The price is kept the same for the sake of comparison, but in small steel foundries where some plants are installed, the current consumed in other parts of the works is not sufficient to allow of the total consumption being produced or purchased under ¾*d.* per B.O.T. unit.

Current consumed per week, including overhead electric crane, = 2352 units = 28 units per ton of steel.

	s.	d.	
28 units @ ½d. unit	1	2	per ton.
Fuel and water for crane	0	2	,,
Cost of power per ton of liquid steel =	1	4	,,

Cost of Raw Materials.—Taking the prices of the raw materials as before, and using the same proportions, the total cost of raw materials for 84 tons of liquid steel = £309 8*s*.

∴ Cost of raw materials per ton of liquid steel = £3 13*s*. 8*d*.

Summary of Costs

Cost of plant, £3500.

	£	s.	d.
Depreciation and interest	0	2	3½
Repairs and stores	0	5	0
Fuel	0	4	6
Labour + 50% for management	0	7	6
Power	0	1	4
Raw materials	3	13	8
Total cost per ton of liquid steel . . .	£4	14	3½

General Conclusions.—The cost of liquid steel in the ladle from the three foregoing plants is:—

	£	s.	d.	
2-ton converter plant with 4 converters	4	9	10	per ton.
,, ,, ,, 2 ,, . . .	4	12	8	,,
,, ,, ,, 1 converter . . .	4	14	3½	,,

It will be observed that the saving in the cost per ton of liquid steel produced by the four-converter plant over that produced by the two-converter plant is not very much, since the output per converter is the same in each plant. The principal advantage gained in working the larger plants is that the cost of labour per ton is reduced, and in addition there are also minor savings in the cost of repairs, fuel, and power.

In each of the three plants compared, the cost of steel produced by them has been based upon an output of the same amount from each converter, and the prices of the raw materials and mixtures have been the same. Fourteen heats per converter per day for the working year may be regarded as a good output. Unfortunately, many steel foundries are not favoured all the year round with orders for steel castings which permit of such a regular flow. They are more often either too full of work to deliver goods required by customers, or they are so "slack" that it is necessary to run the steel plant every alternate day of the week.

When a foundry is very busy, it is possible to obtain as many as 18 heats per day from one converter, but this means considerable overtime for the cupola and converter men. The lining of the converter is also punished severely when working at this rate, making the necessary patching very thick, and consequently less secure, and hence shortening the life of the lining and tuyeres. The saving gained by the increased output under such circumstances is not always appreciable in the cost of steel per ton in the ladle, although in other respects rapid output always has its advantages.

Comparison of Costs.—Below a comparison is made of the cost of steel produced by each of the plants referred to when making an average of 10 heats per day instead of 14. In the comparison, the raw materials, stores, and wages of the men employed are taken at the same values.

2-Ton Converter Plant with four Converters

Cost of plant, £10,000.

	14 heats per day.			10 heats per day.		
	£	s.	d.	£	s.	d.
Depreciation and interest	0	1	9	0	2	3
Repairs and stores	0	4	0	0	5	0
Fuel	0	3	11½	0	4	6
Labour + 50% for management	0	5	2½	0	6	6½
Power	0	1	3	0	1	4
Raw materials	3	13	8	3	13	8
Total	£4	9	10	£4	13	3½

2-Ton Converter Plant with two Converters

Cost of plant, £6000.

	14 heats per day.			10 heats per day.		
	£	s.	d.	£	s.	d.
Depreciation and interest	0	2	1½	0	2	6
Repairs and stores	0	4	6	0	5	6
Fuel	0	4	6	0	4	9
Labour + 50% for management	0	6	7	0	7	11
Power	0	1	3½	0	1	4
Raw materials	3	13	8	3	13	8
Total	£4	12	8	£4	15	8

2-Ton Converter Plant with one Converter

Cost of plant, £3500.

	14 heats per day.			10 heats per day.		
	£	s.	d.	£	s.	d.
Depreciation and interest	0	2	3½	0	3	3
Repairs and stores	0	5	0	0	5	9
Fuel	0	4	6	0	4	9
Labour + 50% for management	0	7	6	0	9	0
Power	0	1	4	0	1	4½
Raw materials	3	13	8	3	13	8
Total	£4	14	3½	£4	17	9½

CHAPTER XXII

CONVERTER PLANTS FOR SMALL FOUNDRIES

Bessemer plants of small capacity are becoming increasingly popular in small steel and malleable iron foundries, as well as in the large manufacturing works where many small steel castings are required. The cost of steel produced in these small plants is considerably higher than when steel is made in say 2- or 3-ton converters, but the convenience of being able to make castings as required instead of being disappointed or delayed with bad deliveries is considered by some manufacturers sufficient ground for installing these small plants.

The half-ton converter, or as it is sometimes called the "baby" converter, is most frequently installed by manufacturers referred to above, and sometimes by larger steel foundries as an adjunct to their larger plant. Sizes between ½ ton and 2 tons are found in several foundries.

1-Ton Surface-Blown Converter Plant

General Description.—One-ton plants are designed and constructed after the manner illustrated in Fig. 114, having cupola fixed upon a raised platform behind the converter, and also as shown in Fig. 115, with cupola and converter on the same ground-level. This latter practice is not uncommon, finding favour in Continental and American foundries, as well as in this country. The choice of arrangement of plant is often determined by the conditions and convenience of the foundry and site where the plant is to be installed. Where the cupola can be mounted on a stage, it is easier to run the melted metal direct to converter along a chute, or, as is done in most modern plants, after first weighing it upon the stage. When the cupola is on the ground, the metal has to be tapped into a ladle and then transferred to the converter. The initial cost of the latter plant is less, but the cost of steel produced by both is approximately the same.

As an alternative to the designs shown in Figs. 114 and 115, the high-pressure blower may be arranged to serve both the converter and the cupola, a branch pipe being taken from the converter air main to the cupola, as shown in Fig. 116, p. 230. This practice, however, is wasteful, as the larger blower is doing the work of a low-pressure blower or fan during part of the time of steel making. In both installations the converters are tipped by means of an electric motor. Where it is not convenient to have electric power, hydraulic tipping is arranged.

Sometimes the blowers are belt driven or steam driven instead of being coupled to an electric motor. Steam is not infrequently used for the hoist, and hydraulic lifts are also common in steel foundry practice. These are details which are arranged according to conditions. Much, however, can be said in favour of electrical equipment throughout. In neither of the plants is a crucible furnace shown for melting the physic, but this is included in the cost of the plant.

Operation of the Plant.—The plant is worked every alternate day, as it is necessary to patch and repair both converter and cupola the day following steel making. The sequence of the operation of a 1-ton plant is the same as in

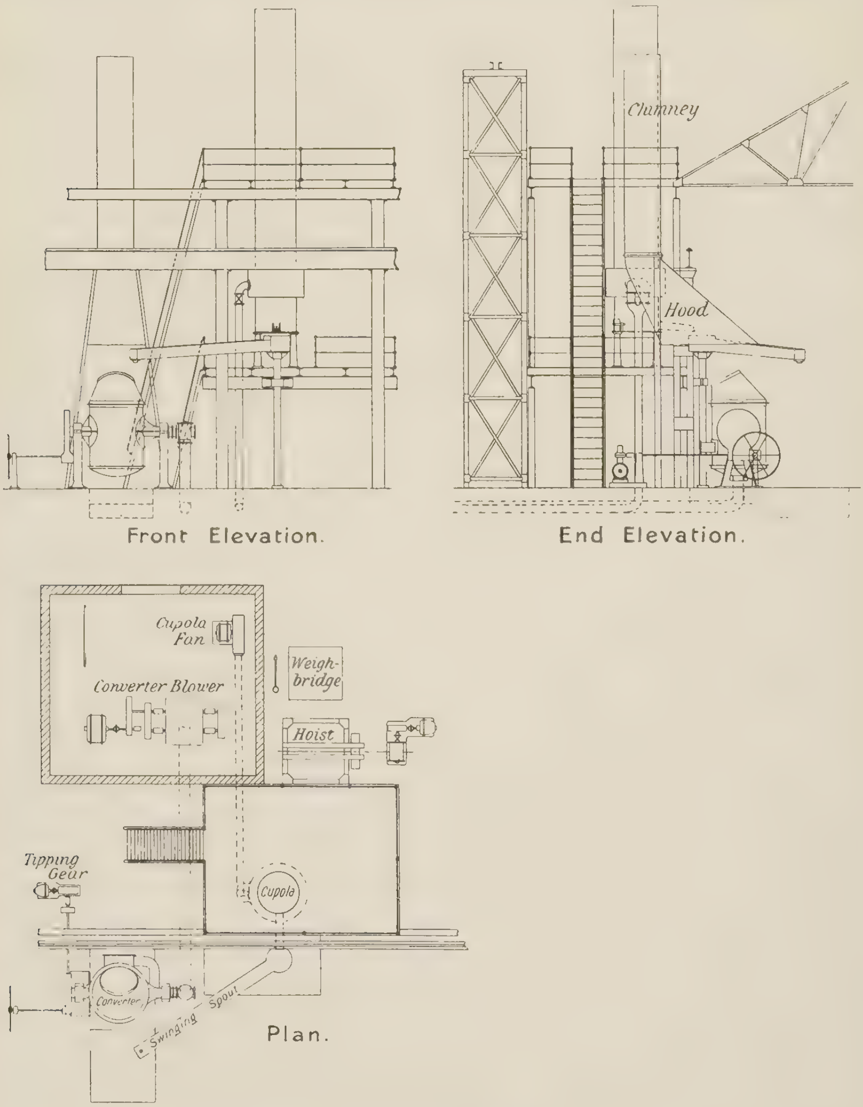


FIG. 114.—Arrangement of One 1-ton Surface-blown Converter Plant. Cupola on staging.

larger plants already described in Chapter XX. The average duration of the blow is, however, somewhat less.

Output and Cost of Plant.—Working either of the plants shown in Figs. 114 and 115 to an average maximum output, 14 heats of 1-ton each could be

obtained during a day of 10 hours. This is equal to 42 tons of liquid steel per week, and approximately 2000 tons per year of 48 working weeks, which will be taken as the output.

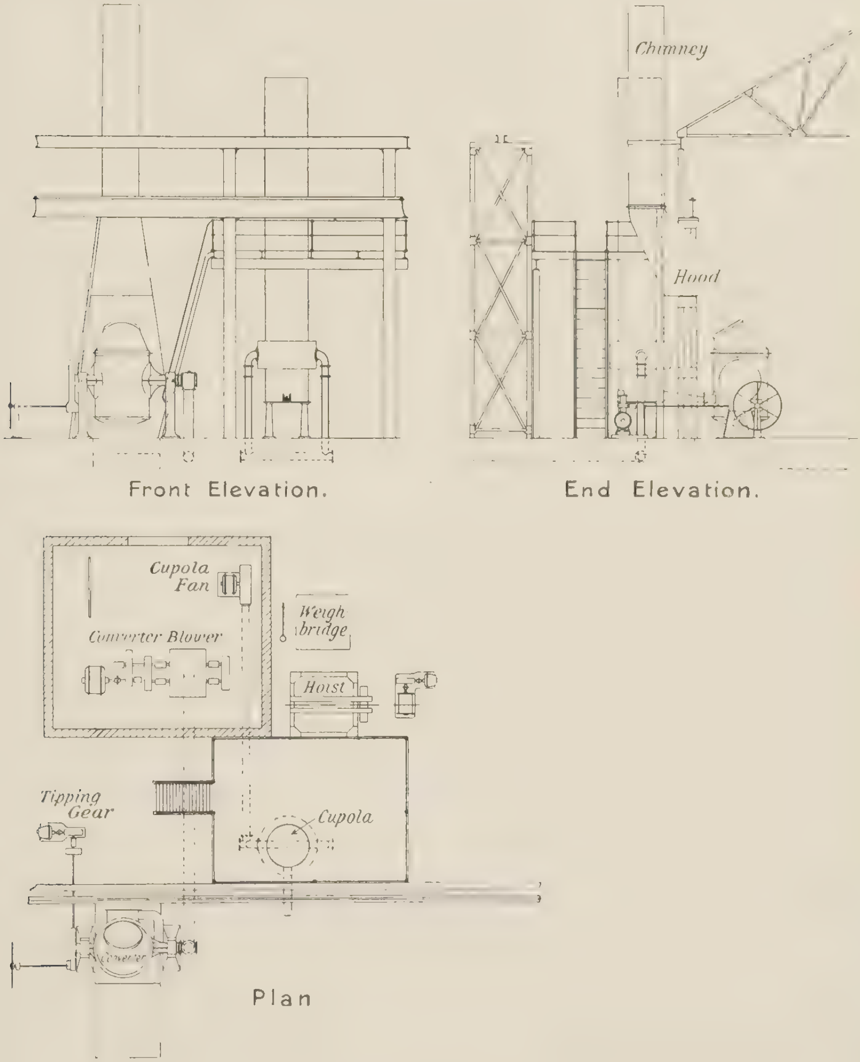


FIG. 115.—Arrangement of One 1-ton Surface-blown Converter Plant.
Cupola on floor-level.

The items included in the cost of the plant, which is approximately £1950, are as follows :—

One 1-ton converter, mounted on pedestals with roller bearings, arranged with tipping gear operated by electric motor and with hand turning gear, together with the necessary electric controller and switch.

One specially designed rapid melting cupola, with all the necessary pipes, valves and gauges.

One high-pressure Roots' blower to supply the necessary blast to the converter through cast-iron pipes and valves coupled to them. Motor and electrical equipment also included.

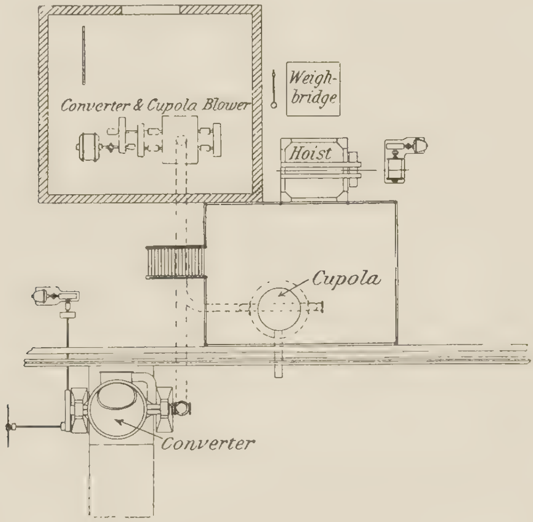


FIG. 116.—Arrangement of One 1-ton Surface-blown Converter Plant with one Blower serving Converter and Cupola.

One fan for cupola, coupled direct to motor.
One electric lift, complete.
One weighbridge for raw materials.
Staging for cupola, suitably covered, and all structural fittings.
One hood and chimney for converter.
One coke-fired crucible melting furnace, with one 4-pot melting hole.
One overhead electric crane (half value included).
Three 30-cwt. ladles.
Blower house with the necessary switchboard and electrical equipment.
All wiring, switches, starters, and electrical accessories.
All blast pipes, spouts, chutes, slag and coke pans, tools, etc.
All brickwork, concrete foundations, pits, linings for converters, cupolas, and ladles.
The whole plant erected complete and set to work.

Allowing a depreciation of 10 per cent. on the complete steel plant, 5 per cent. on the buildings, and $2\frac{1}{2}$ per cent. on the foundations, the annual charge for depreciation is :—

£1650 @ 10%	£165
£100 @ 5%	5
£200 @ $2\frac{1}{2}$%	5
Total . . .	£175

Interest on £1950 @ 5%	£97	10	0
∴ Annual charge for depreciation and interest	£272	10	0

With an output of 2000 tons of liquid steel per year, the charge for depreciation and interest $= \frac{£272\ 10s. \times 20}{2000} = 2s.\ 8\frac{1}{2}d.$ per ton of steel in ladle.

Working Costs (per Ton of Liquid Steel for Carbon Steel Castings)

Cost of Repairs and Stores.—The repairs include all materials and labour expended in patching converter, cupola, ladles, chutes, and crucible furnace, relining converter and cupola periodically, all mechanical and electrical repairs, and tools used about the plant. The stores include all items required.

The average cost of repairs and stores, including labour and materials = 7*s.* 6*d.* per ton of liquid steel.

Cost of Fuel.—The average weight of coke used in heating the cupola, converter, and crucible furnace, and in melting materials = 5 cwts. per ton. Taking coke at 22*s.* 6*d.* per ton, the cost of fuel per ton of liquid steel = 5*s.* $7\frac{1}{2}d.$

Cost of Labour.—The following men are required :—

One converter man.
One cupola and blower attendant.
One cupola charger.
Two charge wheelers.
One man at crucible furnace.
Two men at ladles.
One "blower."
Part wages of one man on overhead crane.

Total wages for time employed during week . £10 15 0

Steel produced in ladle during one week = 42 tons.

∴ Cost of labour per ton of liquid steel = 5*s.* 1*d.*

Adding 50 per cent. as part expenses of chemist and management = 2*s.* $6\frac{1}{2}d.$, the total cost of labour per ton of liquid steel = 7*s.* $7\frac{1}{2}d.$

Cost of Power.—With current supplied at the switchboard at $\frac{1}{2}d.$ per unit, the cost is as follows :—

Current consumed during week = 1344 units.

$$\therefore \text{Cost of power} = \frac{1344 \times \frac{1}{2}}{42} = 1s.\ 4d. \text{ per ton of steel.}$$

Cost of Raw Materials.—Taking the cost of raw materials as before, and using the same mixtures, the price per ton of steel in ladle = £3 13*s.* 8*d.* It should be remembered, however, that pig iron and scrap cannot as a rule be purchased at the same prices per ton in small parcels as in larger quantities, and in foundries where railway trucks cannot conveniently discharge materials into the stockyard, the cost of raw material per ton is increased due to the extra handling. The same price is taken in this cost as before for the sake of comparison.

Summary of Costs

Cost of plant, £1950.

	£	s.	d.
Depreciation and interest	0	2	$8\frac{1}{2}$
Repairs and stores	0	7	6
Fuel	0	5	$7\frac{1}{2}$
Labour + 50% for management	0	7	$7\frac{1}{2}$
Power	0	1	4
Raw materials	3	13	8
Total cost per ton of liquid steel	£4	18	$5\frac{1}{2}$

Costs with Varying Outputs

The following table gives the costs per ton of liquid steel when the foregoing plant is worked on 14, 10, and 6 heats every alternate day, giving 42, 30, and 18 tons of steel per week respectively:—

	14 heats.	10 heats.	6 heats.
Cost of plant, £1950.	£ s. d.	£ s. d.	£ s. d.
Depreciation and interest	2 8½	3 9½	6 4
Repairs and stores	7 6	8 6	9 6
Fuel	5 7½	6 0	6 6
Labour + 50% for management	7 7½	9 0	11 0
Power	1 4	1 6	1 8
Raw materials	3 13 8	3 13 8	3 13 8
Cost per ton of liquid steel	4 18 5½	5 2 5½	5 8 8

Small Bessemer Converters—German Practice

Working Costs

Mr. F. Gebauer of Berlin has sent the following particulars, which have been obtained from German practice. It will be observed that the prices of the raw materials differ from those upon which all the previous calculations are based. Then again, one day's output is compared, not one week's, and certain items of expenditure in connection with cranes and ladles are not included. The following details are given:—

Burden of cupola and converter	400 cwts.
Output—12 charges of 27 cwts.	324 „
Loss and waste in cupola and converter	76 „ (19%).

	£	s.	d.
340 cwts. pig iron @ 70*s*. per ton	59	10	0
54 cwts. steel scrap @ 50*s*. per ton	6	15	0
6 cwts. {ferro-manganese @ 175*s*. per ton; ferro-silicon @ 100*s*. per ton}	2	12	0
48 cwts. coke for cupolas (12% of charge); 10 cwts. coke for heating converter } @ 22*s*. per ton	3	3	9
400 cwt. burden	£72	0	9
Electric power for converter @ 2*s*. 6*d*. per charge	1	10	0
„ „ cupola	0	6	0
Repairing of converter	1	6	0
Wages:—1 foreman	0	10	0
1 melter for cupola	0	5	0
1 workman for cupola	0	4	0
2 workmen for converter	0	8	0
1 workman „ (unskilled labour)	0	3	0
1 „ „ striker	0	4	0
2 men for carrying iron	0	8	0
1 man „ coke	0	4	0
1 engineer	0	4	0
1 bricklayer	0	4	0
5% interest and 10% depreciation on 2000 charges	2	5	0
∴ Cost of 324 cwts. of molten steel	£80	1	9

∴ Cost per ton of molten steel = £4 18*s*. 11*d*.

One-ton Zenzes Converter.—With a one-ton surface-blown Bessemer plant having modifications in design and operation applied by Mr. A. Zenzes, he estimates[1] the cost of molten steel in the ladle as follows, based upon an output of five heats per day and working three days per week.

	£	s.	d.
Raw materials :—			
10·5 tons hematite pig @ £4 per ton	42	0	0
4·5 tons steel scrap @ £3 per ton	13	10	0
15 tons charged	55	10	0
2·7 tons loss in cupola and converter = 18%.			
∴ 12·3 tons of liquid steel in converter.			
Fuel used :—			
1·1 ton coke for heating cupola			
1·1 " " converter and ladles			
1·5 " melting in cupola (10% of charge)			
3·7 tons @ 24s. per ton	4	8	10
0·03 ton limestone per ton of charge	0	5	0
0·615 ton pig additions	2	15	4
0·125 ton ferro-manganese	1	5	0
Power :—			
Cost of power for converter blast	1	10	0
" " cupola blast	0	7	6
Repairs to cupola and converter	1	5	0
Wages of foreman and labour	1	10	0
Total cost	£68	16	8

Total weight of steel in ladle = 13·04 tons.

∴ Cost per ton of liquid steel = £5 5s. 7d.

In the above cost, depreciation of plant and interest on capital are not included.

One Half-ton Surface-blown Converter Plant

General Description.—In small plants, often termed "baby" converters because of their size, many of the features of the larger plants are found. The converter rests upon pedestal bearings, and the tipping is done, as a rule, by means of a handwheel operating suitable reduction gear, instead of by electric or hydraulic power, although in some cases the converter is tipped by power. The converters are so small that they can be lifted from their bearings after the charge has been "blown," and the contents poured direct into a mould. This is not commonly practised unless the overhead cranes are sufficiently powerful to lift converter and charge. It is more often found that the steel is poured from them into shanks and carried to the moulds, hence there is no necessity for a heavy overhead crane. The cupola for melting the charge may be placed on the floor-level near to the converter, as is usually done, or it may be mounted upon a stage. The small high-pressure blower for the converter and the fan for the cupola are of the ordinary types already described. These are usually placed as near to the cupola and converter as convenience will permit.

Operation of the Plant.—Figs. 117, 118, 119 and 120 are photographs of a half-ton Tropenas converter in operation. Fig. 117 shows the charge being

[1] "Foundry Trade Journal," 1911, p. 700.

FIG. 117.—½-ton Tropenas Converter being charged.

FIG. 118.—½-ton Tropenas Converter during Blow.

FIG. 119.—½-ton Tropenas Converter. Charge being poured into Ladle.

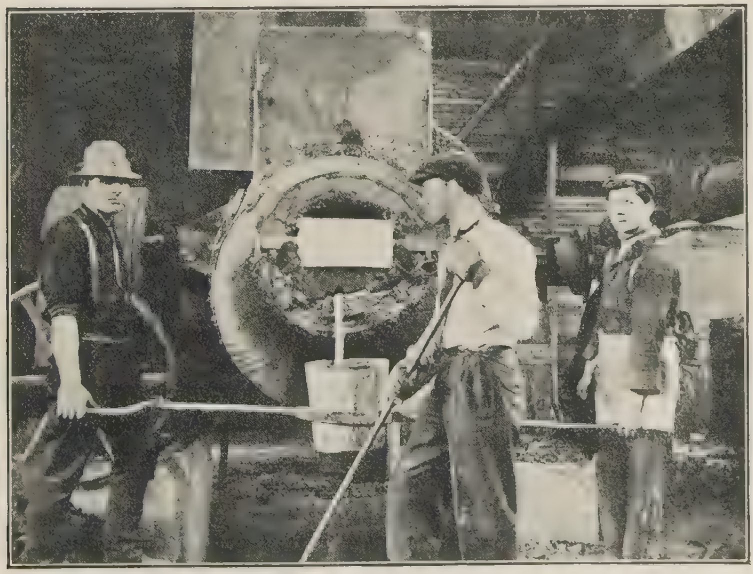


FIG. 120.—½-ton Tropenas Converter. Charge being poured into Shank.

tipped from a ladle into the converter. An overhead crane is employed for carrying the molten iron in the ladle from the converter, and in Fig. 118 the flame is seen issuing from the converter, showing the progress of the blow, which lasts from ten to twenty minutes according to the temperature and nature of the iron treated. Figs. 119 and 120 illustrate two methods of taking steel from the converter. In one instance a ladle suspended from an overhead crane is about to take the whole charge; in the other, the liquid steel is being poured into small shanks. It will be observed that in Fig. 120, the mouth of the converter is partially closed with ganister held in position by a cross-bar and plate, the steel passing through a small hole into the shanks. This prevents slag from mixing with the steel unduly, and enables the use of narrow-mouthed shanks for steel distribution.

Output and Cost of Plant.—The output obtained from a half-ton plant such as is illustrated, is 12 heats in 10 hours, and by working every alternate day, 18 tons of steel could be obtained per week, or 864 tons of liquid steel per year.

The approximate cost of the plant is £1100, and includes the following items :—

One converter, having pedestals with roller bearings and arranged with hand tipping gear only.
One high-pressure blower for supplying the blast to the converter and coupled direct with electric motor. All pipes and valves between blower and converter supplied.
A specially-designed cupola for melting iron and steel scrap.
One fan for cupola—motor driven.
One coke-fired crucible melting furnace, with one 2-pot hole for melting physic.
One weighing machine for charges.
Two 15-cwt. ladles.
One overhead electric crane (half cost).
One hood and chimney for converter.
Structural steelwork, including staging for cupola and suitable roofing.
Blower house with the necessary switchboard equipment.
All necessary pipes, valves, etc., and electrical equipment.
All brickwork, concrete foundations, pit, lining for converter and cupola.
The whole plant erected complete and set to work.

Allowing a depreciation of 10 per cent. on the complete steel plant, 5 per cent. on the buildings, and $2\frac{1}{2}$ per cent. on the foundations, the annual charge for depreciation is :—

	£	*s.*	*d.*
£950 @ 10 %	95	0	0
£50 @ 5 %	2	10	0
£100 @ $2\frac{1}{2}$%	2	10	0
Total . .	100	0	0
Interest on £1100 @ 5%.	55	0	0
Total annual charge . .	£155	0	0

With an output of liquid steel of 864 tons per year, the charge for depreciation and interest $= \frac{155 \times 20}{864} = 3s.\ 7d.$ per ton of liquid steel.

Working Costs (per Ton of Liquid Steel for Carbon Steel Castings)

Cost of Repairs and Stores.—The linings of these small converters are sometimes rammed with a highly refractory sand composition, but it is doubtful if the cost of repairs is thereby reduced. The cost below is based on the use of silica brick lining and the usual ganister for patching. All items of repair about the cupola, converter, crucible furnace and ladles are included, and all mechanical and electrical repairs, together with the necessary stores. Cost of labour and materials per ton of steel in ladle = 8*s.* 6*d.*

Cost of Fuel.—The average weight of coke used in heating the cupola, converter, and crucible furnace, and in melting materials, is equal to 5½ cwts. per ton of steel in ladle. Taking the price of coke at 22*s.* 6*d.* per ton, the cost of fuel per ton of liquid steel = 6*s.* 2*d.*

Cost of Labour.—The labour required includes the following :—

One converter man.

One cupola man.

One charge wheeler.

Two men at ladles and crucible furnace.

One "blower."

Part wages of man at overhead crane.

Total wages for time employed during week, £7 4*s.*

Steel produced in ladle during one week, 18 tons.

∴ Cost of labour per ton of liquid steel = 8*s.*

Adding 50 per cent. for part expenses of chemist and management, the total cost = 12*s.* per ton.

Cost of Power.—On the assumption that electric current can be supplied at the switchboard at ½*d.* per unit, the cost is as follows :—

Current consumed during week, 600 units = 1*s.* 5*d.* per ton of steel.

Cost of Raw Materials.—Calculating upon an 18 per cent. waste during the process of melting and conversion, and with pig iron at 65*s.* and scrap at 50*s.* per ton, the cost of raw materials and physic per ton of steel in ladle, using 30 per cent. scrap charges, = £3 17*s.* 6*d.*

Summary of Costs

Cost of plant, £1100.

	£	*s.*	*d.*
Depreciation and interest	0	3	7
Repairs and stores	0	8	6
Fuel	0	6	2
Labour + 50 per cent. for management	0	12	0
Power	0	1	5
Raw materials	3	17	6
Total cost per ton of liquid steel	£5	9	2

Tropenas "Baby" Converter Plant

Cost of Steel per Ton.—The following costs have been supplied by the Tropenas Converter Co., New York, and are based upon a converter of 1000 lbs. capacity, working 2 days only per week and producing 12 heats per day. No furnace is used for melting the additions added to the charge after the blow, the physic being added in the solid state. This, of course, is a common practice in this country when making steels of low carbon content. Even then

it is always advisable to heat the ferro-manganese before putting it into the charge, as there is otherwise a danger of lowering the temperature of the steel too much.

Analysis of pig iron used :—

Carbon	3·8 to 4·5 %
Silicon	0·5 to 2·0 %
Manganese	1·8 to 3·0 %
Phosphorus	0·06 %
Sulphur	0·05 % (maximum).

Cost of production :—

	£.	s.	d.
9700 lbs. pig iron @ 87*s.* 6*d.* per ton	18	10	10
4900 lbs. steel scrap @ 62*s.* 6*d.* per ton	6	17	6
2100 lbs. coke for cupola @ 16*s.* 8*d.* per ton	0	15	7½
620 lbs. limestone @ 10*s.* 5*d.* per ton	0	3	4
One man and helper for cupola	0	16	8
10 h.p. for cupola blower @ 2½*d.* per k.w. hour	0	7	11
300 lbs. coke for converter	0	2	6
30 h.p. for 3 hours for converter blower @ 2½*d.* per k.w. hour	0	14	2
One man and helper on converter	0	18	9
1460 lbs. ferro-silicon @ 116*s.* 8*d.* per ton	4	5	5
216 lbs. ferro-manganese @ 187*s.* 6*d.* per ton	1	0	2½
Aluminium	0	2	11
Linings for cupola and converter	1	0	10
Power for elevator and tilting converter	0	4	7
General expenses of manufacturing	5	4	2
Total	£41	5	5

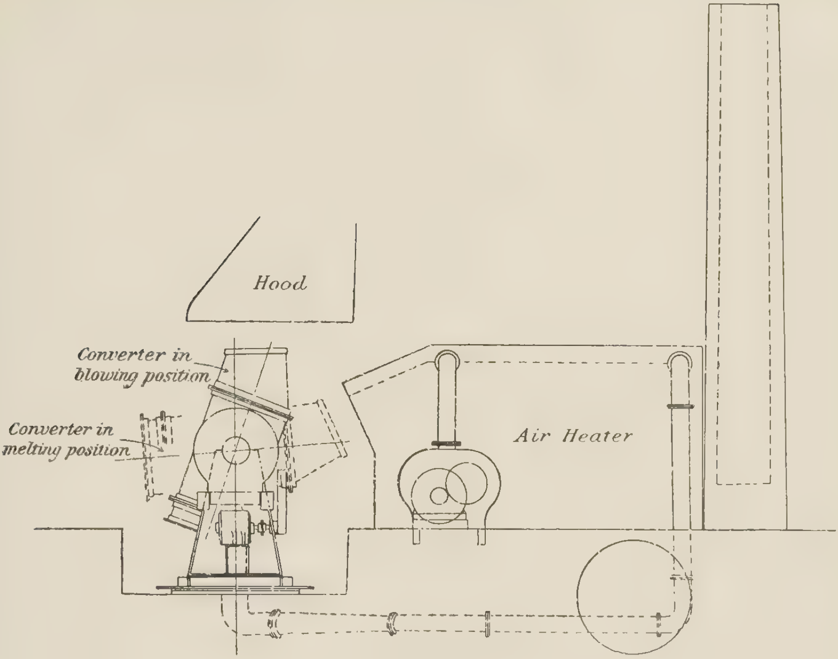
The cost of liquid steel in ladle = £6 17*s.* 7*d.* per American ton (2000 lbs.), or £7 14*s.* 6*d.* per English ton.

It will be observed that the prices per ton of pig iron and scrap are much higher than the English prices upon which all the other costs have been based. The price likewise does not include charge for depreciation of plant and interest on capital.

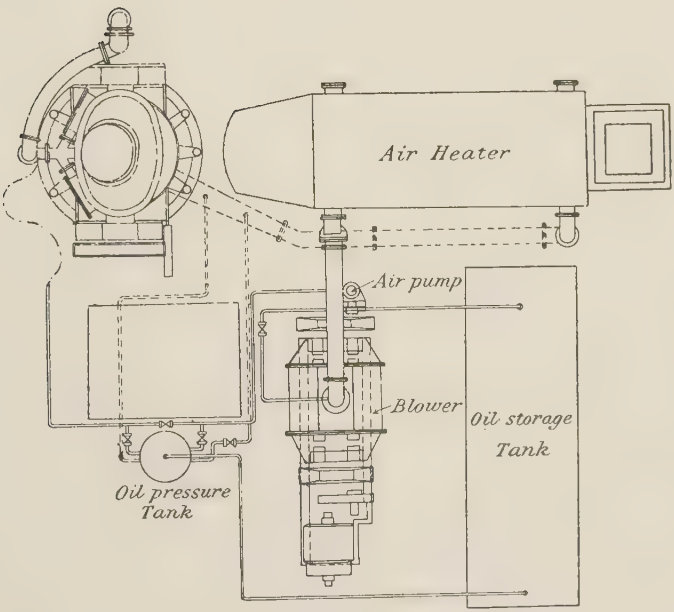
The Stock Patent Oil-Fired Converter.

General Description.—The special outstanding features of the Stock converter are found in the use of the converter vessel for melting the charge, instead of the cupola or other melting furnace; and in using hot blast in the conversion of the metal when melted, the blast being heated by the waste gases from the fuel used during the process of melting. The employment of oil for melting is also an important feature, inasmuch as no sulphur is imparted to the material during melting, as is the case when pig iron and scrap are melted in the cupola with coke as fuel.

The plant consists of one converter mounted upon pedestals with roller bearings, which are fixed to a turntable capable of rotation in a horizontal plane. The movement of the turntable and the tipping of the converter are both obtained by means of electric motors operating through suitable gearing. The 3-ton converter has one single row of tuyeres, seven in number, each 1¾ inches diameter. The blast box is so arranged that the seven oil jets can be fixed in the tuyeres ready for use in less than one minute. When the melting is completed they can be removed from the tuyeres and the plugs put into the



Elevation.



Plan.

FIG. 121.—Arrangement of Stock Converter Plant.

blast-box cover and the converter placed for blowing, in less than two minutes. The converter is lined with silica bricks in the ordinary way.

One high-pressure blower of the Roots' type is used for supplying the air for melting and converting. It is coupled direct to an electric motor mounted upon an extension of the blower bedplate. Instead of the pipes being carried from the blower direct to the converter, they are coupled to a series of pipes arranged in a brick chamber which receives the waste heat from the converter during the melting process on its way to the chimney. The other end of the series of pipes is connected with the converter.

The heating chamber bears a strong likeness to a Green's Economiser, but instead of water passing through the pipes to feed the boiler, air is passed through them for the converter. The construction of the pipes and joints in the heating chamber allows for liberal expansion and contraction due to the change of temperature. At the mouth of the chamber where the gases enter, a wall of chequered brickwork is placed, and in this manner a good temperature is maintained just where the air enters the heated zone on its way to the converter. The temperature of the air as it enters the converter is raised by this means to about 260° C.

In the general arrangement[1] of the plant, shown in Fig. 121, it will be observed that the oil storage tank or reservoir is placed near the blower house. It is convenient to place the tank in proximity to the railway siding to facilitate loading and unloading supplies of oil. The oil is pumped from the tank to the converter vessel through suitable pipes and valves terminating in a flexible tube, which is connected to the oil burners fixed in the blast box of the converter.

The electric and blast controlling gear are placed in the blower house within easy reach of the operator while he is watching the blow.

Operation of the Plant

Heating the Converter.—As the melting of the pig iron and scrap is carried out in the converter, it is necessary to heat the vessel before charging the raw materials. This is done in the usual way by lighting a wood and coke fire and allowing the brick lining to become hot. The coke is then removed, the oil jets introduced, and the blower started. A pressure of air of about $\frac{1}{2}$ lb. to $\frac{3}{4}$ lb. per square inch is applied during the heating, which usually takes about one hour. The temperature of the vessel after one hour's heating is from 1500 to 1600 degs. C. The oil consumed during the hour is about 50 to 55 gallons. During the operation the converter is lying in the horizontal position with the hot gases issuing from its mouth into the heating chamber.

Charging the Raw Materials.—The materials are charged into the converter while it is lying in the horizontal position at right angles to the blowing position. Three men are employed for the operation—one man holds an ordinary "peel," which rests on a bar fixed across the mouth of the converter, and which he pushes forward with the pig iron placed upon it alternately by the other two men. Only six minutes are taken to charge about 45 cwts. After charging, the converter is turned round its vertical axis with its mouth in line with the heating chamber, and the melting is commenced.

Melting.—The pressure of air used during melting is about $\frac{3}{4}$ lb. per square inch, and the oil consumed about 30 gallons per ton of material melted. During the process it is usual to turn the vessel round in order to examine the charge and stir the metal when it becomes fluid. The time taken in melting is from $1\frac{1}{2}$ to $1\frac{3}{4}$ hours for 45 cwts. of pig iron. Immediately the melting is completed, the oil jets are removed from the blast box, the vessel tilted, the level of the

[1] Illustrated by kind permission of Messrs. Thwaites Bros., Ltd., Bradford.

metal sighted, the plugs fixed in the blast box, and the blowing commenced; these operations take about two minutes to complete.

Blowing.—At the start of the blow, the air pressure is about $2\frac{1}{2}$ lbs. per square inch, and in from 3 to 8 minutes, according to the temperature of the charge and its composition, the "light" appears. The oxidation of the silicon, manganese, and carbon proceeds in the ordinary manner, and the pressure varies from $2\frac{1}{2}$ to $3\frac{1}{2}$ lbs. per square inch until the blow is completed. This operation lasts from 18 to 25 minutes, at the end of which time the converter is turned down and the physic added in quantity, form, and composition according to the quality of the steel required.

Pouring.—The steel is poured into a ladle suspended from an overhead crane, and afterwards shanked as required. As a rule, its temperature is equal to that of crucible steel used for the thinnest classes of steel castings. The steel can be carried in shanks for a considerable distance, maintaining a good heat until the complete charge is cast.

General Conclusions.—(1) In following the operation of this plant from the heating of the vessel to the pouring of the finished steel, the simplicity, cleanliness, and the small amount of labour required, are very pronounced. The rapid movement of the converter in the horizontal and vertical plane in response to the operator's use of the electrical controller, the freedom of ebullition of slag during the blow, and the ease with which the three men employed get through their work, at once commend the process.

(2) When pig iron of the following analysis is used in the process, steel giving 28 to 30 tons tenacity with 30 per cent. elongation on a length of 2 inches can be regularly obtained after annealing.

Carbon	3·5 to 4·0 %
Silicon	2·0 to 2·3 %
Manganese	1·0 to 1·5 %
Phosphorus	0·03 to 0·04%
Sulphur	0·03 to 0·04%

(3) The drawback to the general adoption of the process lies in the time taken to produce each heat. Where large outputs are required, this objection can be overcome by the use of two or three converters, thereby obtaining 10 or 15 heats of steel respectively, instead of 5 per day from the one converter.

Output and Cost of Plant (3-ton Converter).—With one converter of 3 tons capacity, and one spare converter for use on alternate days, an output of 52 tons of liquid steel per week is taken working 2-ton heats.

The cost of the plant, including one converter mounted on rotating table and operated by motors for tipping and rotating, together with blower and motor and all pipes, one spare vessel, oil tank, chimney, hood, weighbridge,

and overhead crane = approx.	£3300
Buildings and brickwork	500
Foundations	200
Total . .	£4000

Summary of Costs

	£	s.	d.
Charge for depreciation @ 10%, 5% and $2\frac{1}{2}$%, and interest @ 5% .	0	4	5
Repairs and stores	0	9	0
Fuel oil ($40\frac{1}{2}$ gallons @ $2\frac{1}{2}$*d.* gallon)	0	8	5
Labour + 50% for management	0	4	6
Power for plant and crane (44 units @ $\frac{1}{2}$*d.* unit)	0	1	10
Raw materials (pig, 65*s.* per ton and 20% of scrap @ 50*s.* per ton) .	3	18	0
Royalty	0	3	4
Total cost per ton of liquid steel . .	£5	9	6

Fig. 122 shows a half-ton Stock converter being charged with cold pig iron.

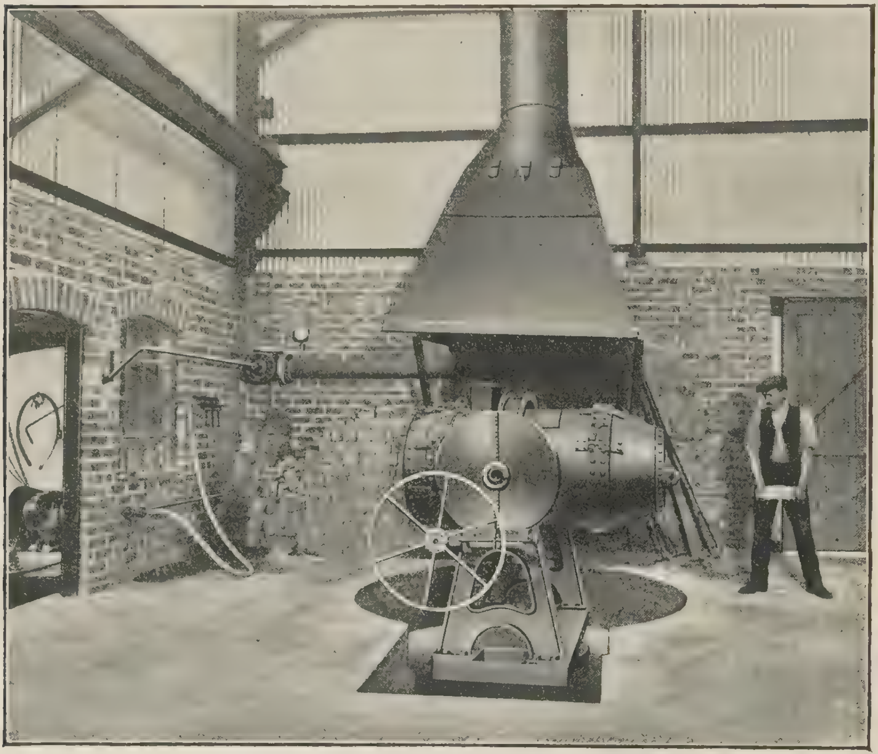


FIG. 122.—$\frac{1}{2}$-ton Stock Converter being charged.

CHAPTER XXIII

COMPOSITION OF CHARGES EMPLOYED AND ANALYSES AND USES OF STEEL PRODUCED IN SMALL BESSEMER CONVERTER PLANTS

STEEL castings weighing from a few ounces to several tons each, are made regularly by small Bessemer converters in Great Britain, Germany, Belgium, France, America, and many other countries. Hot steel can be made by this process that will flow as easily as crucible steel into moulds of intricate design and of very thin section. The increasing number of small plants which are being installed bears testimony to their adaptability for making not only steel for ordinary castings, but for doing work which several years ago was considered too difficult for any but the crucible process.

Uses of Bessemer Steel Castings.—Small Bessemer converters produce steel for railway and tramway trackwork, mining, crushing, colliery, marine, hydraulic, ordnance, naval, electrical, and general engineering steel castings. It is somewhat difficult to say which class of steel castings (ranging in weight from $\frac{1}{4}$ lb. to 30,000 lbs.) could not be made from steel produced by the Bessemer surface-blown processes.

The following may be regarded as typical classes or sections in which steel castings may be grouped, and apply not only to those produced in the surface-blown and all kinds of small Bessemer plants, but to small open-hearth furnace plants and electric furnaces :—

1. General or ordinary steel castings, which include the demands from all branches of engineering, where no tests are specified, and where general wear only is required, and the castings are not subjected to more than ordinary stresses.

   In this section a large number of the castings would not be machined, and those which are machined would be in parts only.
2. Castings which are not subjected to special stresses or undue wear, but are machined on most of their surfaces and require to be sound more for the sake of appearance than for safety.
3. Castings subjected to shocks and rolling wear.
4. Castings which are subjected to excessive wear and stress, but the appearance of their surfaces is not important.
5. Castings subjected to bursting pressure, which require to be sound when machined.
6. Castings for electrical purposes, where high permeability and soundness are of importance.
7. Castings which are specified to give definite physical and chemical tests, according to the purposes for which they are required.

Castings included in the Various Classes.—Castings of the 1st class include :—

(*a*) Colliery and mining wagon, barrow, truck, bogie, and all kinds of wheels, which are bored only in the hole in which the axle fits.

Also all kinds of brackets, pedestals and rollers used in mining and colliery haulage.

(*b*) Rough toothed gears, brackets, pulleys, rakes, etc., used in gas, chemical, and other manufacturing establishments.

(*c*) Marine, hydraulic, ordnance, railway, and general engineering, where various castings are not subjected to special wear or stress.

Castings of the 2nd class include:—

Parts of high class machinery such as guards, covers, brackets, foundation blocks.

Castings of the 3rd class include:—

Gearing of all kinds, and rolling mill pinions, where reversals cause heavy shocks.

Castings of the 4th class include:—

(*a*) All the wearing parts of crushing, stamping, grinding, dredging, and screening machinery used in mines, quarries, dredgers, cement works, steelworks slag plants, refractory material works, and elsewhere, including—crusher jaws, cheek plates, toggles and grooves, stamp heads, shoes, dies, wearing and screening plates, hunch plates, knives, balls, mantles, concaves, etc., which demand the toughest and hardest material.

(*b*) Trackwork for railways and tramways, such as special intersection work, including points, crossings, special rails, etc.

Castings of the 5th class include:—

Hydraulic cylinders, pump bodies, valve castings, air chambers, gas and steam-engine cylinders, etc.

Castings of the 6th class include:—

All kinds of castings for electrical purposes such as motor cases, frames, poles, and covers.

Castings of the 7th class include:—

(*a*) Railway and wagon wheel centres, horn blocks, bolsters, buffers, frame stays, and all other castings for locomotives, carriages, and wagons.

(*b*) Bridge bearings, foundation blocks, and other bridge castings subjected to stress.

(*c*) Wearing parts of machinery for ships, also anchors, bollards, etc.

(*d*) Ordnance steel castings for gun carriages, etc.

Analyses of Castings in the Various Classes.—The table on next page gives the analyses of steel suited for each class of casting.

The above list of analyses does not represent all the kinds of steel made by the steel founder. The aim, however—and rightly so—of steel casting makers, is to reduce as much as possible the number of kinds of steel manufactured, as cost and confusion are thereby minimised.

Castings supplied to Specification.—All classes of steel castings, except those used for electrical work, *vide* Class 6, are usually annealed. In the case of manganese steel castings they are specially treated. Different kinds of castings supplied to the specifications of engineers and others are too numerous to mention, but two analyses are given under Class 7, of steel suitable for castings having wearing surfaces, and locomotive and wagon castings. The British Engineering Standards Committee has done something to reduce the number of specifications which exist for the same class of castings, but very often the requirements of specifications are too exacting, particularly over non-essentials, and some conditions stipulated are impossible to fulfil. Steel manufacturers who undertake test-work often groan under restrictions and conditions against which their common sense and practical knowledge rebel. Sooner than run the risk of rejections, they refuse the work or quote a price which prevents

TABLE LXII

ANALYSES OF VARIOUS STEEL CASTINGS

Class.	C %	Si %	Mn %	P %	S %	Cr %	Remarks.
Class 1. Ordinary castings	0·4 –0·45	0·3 0·4	0·75– 0·8	0·07	0·06	—	
,, 2. Machined ,, ...	0·3 –0·35	0·5–0·6	0·8 – 0·9	0·06	0·05	—	
,, 3. Gearing, light	0·65–0·75	0·4–0·5	0·7 – 0·8	0·05	0·04	—	
,, ,, ,, heavy	0·35–0·45	0·2–0·3	0·7 – 0·8	0·05	0·04	—	
,, 4. Crushing and wearing . . .	1·0 –1·25	0·2–0·3	10·0 –12·0	0·06	0·05	—	
,, ,, ,, ,, . . .	0·7 –0·8	0·4–0·5	0·75– 0·85	0·06	0·05	0·5–1·0	
,, 5. Castings under pressure . . .	0·4 –0·6	0·4–0·6	0·8 – 0·9	0·06	0·05	—	
,, 6. Electrical work	0·1 –0·2	0·1–0·3	0·2 – 0·4	0·06	0·05		
,, 7. Test work { Castings with wearing surfaces . .	0·35	0·4–0·45	0·75– 0·85	0·04	0·03	—	Engineering Standards Committee's Standard Specification for Steel Castings.
,, 7. Test work { Other general castings and wheel centres . . .	0·2 –0·25	0·2–0·25	0·5 – 0·6	0·04	0·03	—	35 tons tensile, 10% elong. on 2″. 26 ,, ,, 15% ,, ,, 2″.

the orders being placed with them. Other manufacturers who undertake the work and find it difficult or impossible to comply with the tests demanded, are tempted to adopt doubtful means by which the tests are made to pass inspection.

The following list of specifications gives some idea of the variation in the tests called for from castings used for similar purposes:—

TABLE LXIII

SPECIFICATIONS FOR STEEL CASTINGS

Company.	Kind of castings.	Tenacity tons per sq. inch.	Elongation % on 2″.	Other conditions.
G. C. Railway (1910) .	Quality A. Castings with wearing surfaces	40 to 45	12	S and P not more than 0·07%.
,, ,, (1910) .	Quality B. Other general castings	30 to 34	24 to 20	S and P not more than 0·07%.
,, ,, (1910) .	Wheel centres	28	24	1″ round bend, 90° round 2½″ bar. S and P not more than 0·05%.
Caledonian Railway (1900)	Wheel centres	32	—	
Central Argentine Railway (1911)	Wheels for rail trolleys	34 to 38	6	
G. W. Railway (1898) .	Loco castings	28 to 34	20	90° bend.
,, ,, (1908) .	Wagon wheel centres and ordinary castings. Important general castings and loco and tender wheel centres	26	15 on 3″	90° bend over 2½″ round bar, without fracture. Drop tests for centres.
,, ,, (1908) .	Castings with wearing surfaces	35	10 on 3″	
G. N. S. Railway . .	Ramps, double	28 to 32	25	1″ sq. bend, 90° over 1½″ bar.
London County Council	Wheel centres	30 to 37	10	1″ round bend, 60° over 3″ bar.
Midland Railway (1905)	Wheel centres	28 to 34	20	1¼″ sq. bend, 60° round a ⅝″ radius. S and P not more than 0·05%.

Test pieces are sometimes cast separately from the same heat as is used for the castings. As a rule this is only permitted when the castings are not large enough to admit of test pieces forming a part of the casting, or where any risk to the castings is likely to follow by having the test pieces cast on them.

Two pieces, one for tensile and the other for bend test, are cast with each casting in each heat. All the test pieces, however, are not used, selections only being made and tested from each heat at the will of the engineer or inspector. Should the first tests fail, a sufficient number of pieces remain for repeated tests.

Chemical analyses and physical tests are not often specified together, engineers and others being content to specify limits for the phosphorus and sulphur only, with the physical tests. This is a sensible arrangement, as it leaves the steel maker a free hand to make what steel he chooses, provided it complies with the physical tests. The stipulation regarding phosphorus and

sulphur is necessary, as the proportions of these elements in the steel afford a fairly accurate index of its purity. The presence of copper in steel is also objectionable, and the maximum amount allowable in the steel should be specified.

Composition of Charges (Acid Bessemer).—In small Bessemer plants, the charges consist of pig iron and steel scrap melted together in varying proportions.

With a charge consisting of pig iron only, it is necessary to use a low silicon pig so that the cupola metal will contain from 1·5 to 2 per cent. of silicon when ready for the converter. In charges where high percentages of scrap are melted it is necessary to use pig iron containing 4 per cent. of silicon, or even more, in order to obtain a sufficient silicon content in the metal before blowing. To work economically it is necessary to use all the scrap produced in the manufacture of castings in the foundry, which amounts to from 20 to 40 per cent. of the total steel made, according to the class of castings produced. As a rule it is found advisable to buy other scrap to mix with the foundry scrap and increase the percentage used in the charge, thereby reducing the amount of pig iron, which usually costs more than scrap. For ordinary foundry castings, of which tests are not required, this practice is economical provided the scrap is not too dirty. Old rail scrap is fairly reliable, as the amounts of phosphorus and sulphur in it are known, or can be estimated without much cost. Miscellaneous light scrap is not so good, and it is very often a source of trouble and more costly in the end (although bought more cheaply in the first instance) than the heavier and more reliable scrap.

For steel castings made to specification, miscellaneous cheap scrap should not be used for making steel in small Bessemer plants. Its use in the Siemens furnace is a different matter, where tests can be taken and analyses made during the progress of the melt, which is impossible in the Bessemer process.

In the acid Bessemer converter it is not possible to remove phosphorus or sulphur from the charge during the process, and it is therefore essential to watch the materials used—both pig and scrap.

Charges.—The following charges are suitable for steel castings of ordinary quality, such as are given in Table LXII, classes 1 to 6; the only difference in the manufacture of one class over another being in the composition and quantity of materials used as physic additions to the blown metal. The charges are melted in the cupola, and the following are typical of high and low pig iron charges with corresponding amounts of scrap:—

Charges melted in the Cupola

(1) Charge with high percentage of pig iron:—

Hematite pig iron (3·5% Si)	7 cwts.
Rail end and steel castings scrap	3 ,,
Limestone	40 lbs.
Fluorspar	10 ,,
Coke	1 to $1\frac{1}{2}$ cwts.

(2) Charge with high percentage of scrap:—

Hematite pig iron (4% Si)	4 cwts.
Rail end and steel castings scrap	6 ,,
Limestone	45 lbs.
Fluorspar	10 ,,
Coke	$1\frac{1}{4}$ to $1\frac{3}{4}$ cwts.

For the above charges, the pig iron could be selected from any of the brands named in Table VIII, or from other hematite irons of similar analyses.

It is often found advisable to vary the composition of the first few charges

melted in the cupola each day, as the cupola metal is not as hot for the first heat as in the subsequent heats. The variation consists of the use of a little more pig iron and less scrap, or from 5 to 10 per cent. of pig iron containing 10 to 12 per cent. of silicon. Each melter humours the early charges slightly, in order to obtain the best results.

The following is an ordinary composition for the first four cupola charges each day, when working with 10-cwt. charges :—

Pig iron, $3\frac{1}{2}$% silicon	$5\frac{1}{2}$ cwts.
Rail and foundry scrap : equal proportions . .	4 ,,
Pig iron, 12% silicon	$\frac{1}{2}$ cwt.

In the examples of typical cupola charges, the weights given are 10 cwts., but it is not necessary to abide by this quantity. Often as much as 14-cwt. charges of pig and scrap are used, the amount of coke between each charge of metal being correspondingly increased.

Whatever the nature of the charge used, the result of the melt should produce cupola metal having sufficient silicon, manganese, and carbon to give a rapid conversion from cupola to blown metal in the converter. In this country, the practice is to obtain metal from the cupola which will contain from 1·5 to 2·0 per cent. of silicon, with manganese from 0·5 to 1·0 per cent. The carbon is usually over 3 per cent., even when 60 to 70 per cent. of scrap is used, as the coke gives up its carbon to the metal during the melt. This practice, however, is subject to variation, as the pig irons used in other countries do not contain the same percentages of silicon and manganese. The following analyses of cupola metal ready for conversion to steel, are typical of English practice :—

TABLE LXIV

ANALYSES OF CUPOLA METAL

Nature of charge.	Percentage of silicon in pig iron melted.	Analyses of cupola metal.				
		C %	Si %	Mn %	P %	S %
High percentage of pig iron and low percentage of scrap	3·5	3·5	2·0	0·9	0·05	0·04
High percentage of scrap and low percentage of pig iron	4·0	3·3	1·5	0·7	0·06	0·05

The following table gives the analyses of the charges of blown metal before the additions are made :—

TABLE LXV

ANALYSES OF METAL IN BESSEMER CONVERTER AFTER THE BLOW AND BEFORE THE ADDITIONS ARE MADE

Nature of charge.	Percentage of silicon in pig iron melted.	C %	Si %	Mn %	P %	S %
High percentage of pig iron and low percentage of scrap	3·5	0·1	Trace	0·075–0·1	0·03	0·03
High percentage of scrap and low percentage of pig iron	4·0	0·09	Trace	0·075–0·1	0·04	0·04

Mr. Percy Longmuir[1] gives in the following table, the analyses of cupola metal before being blown in the converter, and also shows the progress of the blow at 5, 12, 14 and 18 minutes. In the last column of the table, the analysis given of finished metal is that of good average mild steel castings, and was obtained by making suitable additions of ferro-alloys to the metal in the converter at the end of the blow. Steel of different analyses could, of course, be obtained from the same blown metal by varying the amount and kind of ferro-alloys and pig iron additions.

TABLE LXVI

ANALYSES OF METAL DURING "BLOW"

	Cupola metal.	After 5 mins. blowing.	After 12 mins. blowing.	After 14 mins. blowing.	After 18 mins. blowing.	End of blow.	Finished metal.
Graphite . . .	3·18	2·92	—	—	—	—	—
Combined carbon .	0·35	0·34	2·92	2·3	0·86	0·1	0·24
Silicon	2·31	1·62	0·466	0·382	0·084	0·074	0·326
Sulphur . . .	0·037	0·037	0·035	0·036	0·038	0·038	0·037
Phosphorus . .	0·054	0·053	0·054	0·054	0·051	0·050	0·058
Manganese . .	0·61	0·60	0·101	0·04	0·040	0·042	1·080

Loss of Metal in Melting and Blowing.—In the melting of the charge in the cupola, from 2 per cent. to 4 per cent. of the weight of the pig iron and scrap is lost owing to oxidation. The cleaner the scrap the lower the loss.

During the process of converting the iron into steel, from 10 per cent. to 12 per cent. is lost in oxidising the metalloids and the iron in the charge.

Test Work.—Castings supplied to specifications given under class 7, Table LXII, p. 245, are often made from charges similar to those on page 247. The pig iron used in these charges will produce steel castings which when suitably treated by annealing will give satisfactory results. It is, however, better to use pig iron containing not more than 0·03 per cent. of phosphorus and sulphur when working to specifications where a high elongation is demanded from the test pieces, as for example in wheel centres, where the requirements are—

28 tons per square inch tenacity,
24 per cent. elongation on 2 inches.

For this class of work it is often advisable to use a low silicon pig iron charge only, or if a proportion of scrap is added, its analysis should be known, and the scrap only used if low in sulphur and phosphorus.

With reference to the presence of sulphur in steel, it has been proved that when in the form of manganese sulphide it is not a dangerous element. Professor Arnold, F.R.S., who made the valuable discovery that the whole of the sulphur in steel separated in the free state as sulphide of manganese when there was sufficient manganese to combine with it, showed from his investigations[2] that "Sulphide of iron is deadly in its effect upon steel, whilst sulphide of manganese is comparatively harmless."

Mr. H. H. Campbell,[3] in summing up his series of investigations on the strength of open-hearth steels, states that "the effect of sulphur on the strength of acid and basic steel is very small."

While on a visit to the United States in 1912, we had the opportunity of

[1] Paper on "Steel Foundry Practice," read before the Manchester Association of Engineers, Feb. 26th, 1910.

[2] "Journal Iron and Steel Institute," 1903, I, p. 142.

[3] *Ibid.*, 1904, II, p. 61.

witnessing the rolling of ingots of basic steel, which contained 0·15 per cent. of sulphur. At the works where the rolling was done it was found that by gradually increasing the amount of sulphur, with a corresponding increase in the manganese content, a better finish was obtained in the machined products made from the steel. The manganese in the steel was 0·65 per cent., and the phosphorus 0·025 per cent. With a lower percentage of manganese the ingots cracked while being rolled.

Dr. J. E. Stead, F.R.S., says[1] it used to be considered that manganese should be in at least six times the proportion of sulphur, and his own experience was that it was safer to have eight times as much. He had met with steel rails containing as much as 0·16 per cent. of sulphur, giving good results in this and other countries.

All these, and other investigations, have shown that sulphur is something to be reckoned with in steel, and while its presence in even comparatively large percentages in the form of manganese sulphide has proved to be of little harm, its absence in pig iron gives a more reliable result, particularly when used for steel castings either in the Bessemer or Siemens processes.

The question of cost is often the determining factor in the use of high or low sulphurous pig iron in steel manufacture, as steel makers from practical experience know that the results obtained from pig irons with a low sulphur and phosphorus content, are better than from pig irons having high sulphur and phosphorus contents.

Composition of Additions to Converter Charges.—The materials used for physicking the charges of blown metal vary in composition and weight according to the kind of steel required and the weight of the charge. Before any additions are made, the blown metal in the converter contains as a rule about 0·1 per cent. of carbon, so that when a soft steel is required such as in Class 6, Table LXII, p. 245, the additions necessary to give the desired analysis consist of a small amount of ferro-manganese and ferro-silicon. When, however, a high carbon steel is required, such as in Class 4, Table LXII, p. 245, several hundredweights of pig iron, as well as additions of ferro-manganese and ferro-silicon, must be added to give the required carbon, manganese, and silicon to the steel.

Method of adding Physic to Charge.—When only small percentages of ferro-manganese and ferro-silicon are required, they are sometimes added in the cold state to the blown metal in the converter before the steel is poured into the ladle. By this method a considerable loss of manganese takes place, which is usually reckoned at 40 per cent. When the ferro-manganese is put into the ladle and the metal poured upon it from the converter, a smaller loss of manganese (about 20 per cent. to 25 per cent.) results. When very liquid steel is required for thin intricate castings it is at least necessary to make the ferro-manganese and silicon hot before putting them into the ladle. When pig iron is used for carburising it is sometimes added solid by throwing it into the converter, after dipping it in water. It is, however, more usual to melt the pig iron and add it to the ladle or the converter in the liquid state. By this means the steel is kept more fluid than when solid materials are added.

The materials used as a rule for additions are :—

(1) Pig iron (cupola metal), containing from 1·75 to 2·25 per cent. silicon, 3·4 to 3·5 per cent. carbon, and from 0·5 to 1·0 per cent. of manganese.
(2) Ferro-manganese.
(3) Ferro-silicon.
(4) Special ferro-alloys, such as ferro-nickel, ferro-chrome, etc.
(5) Calcium silicide and aluminium, to "kill" the steel.

Ferro-alloys are manufactured which contain different percentages of the

[1] "Journal Iron and Steel Institute," 1903, I, p. 147.

special metals; analyses of these are given in Chapter II, Section VI, which deals with ferro-alloys.

Method of finding the Amount of Material required to be added to Blown Metal.—The weight of the charge to which the additions are to be made is taken as two tons, and the analysis of the finished steel required is as follows :—

Carbon	0·40 to 0·45 %
Silicon	0·3 „ 0·4 %
Manganese . . .	0·75 „ 0·8 %
Phosphorus . . .	0·05 „ 0·6 %
Sulphur	0·04 „ 0·05 %

The blown metal in the converter usually contains about 0·1 per cent. of carbon, and traces of silicon and manganese which can be neglected when calculating the necessary additions. The phosphorus and sulphur in the blown metal depend upon the purity of the cupola metal, and are not diminished appreciably by reason of the additions.

Materials to give the analysis required.

Assuming that the carbon in the blown metal is 0·1 per cent., then 0·3 per cent. of carbon must be added to make up the minimum percentage required. By adding molten pig iron from the cupola, the blown metal is enriched by carbon, silicon, and manganese, as the cupola metal contains about :—

Carbon	3·4 to 3·5 %
Silicon	1·75 „ 2·25%
Manganese . . .	0·5 „ 1·0 %

It does not, however, contain these elements in the proportions to produce the analysis required, without additions of ferro-manganese and ferro-silicon. The proportion of ferro-manganese to be added to the pig iron must be determined by trial and error, and it is common to find the amount of ferro-manganese first, and afterwards the pig iron. In finding the percentages of carbon, manganese, and silicon required for the charge, the weight of the additions must be estimated and included in the weight of the charge. For steel having the analysis above mentioned, the approximate weight of the additions is 3 cwts., therefore the weight of the total charge is taken at 43 cwts.

Ferro-manganese required.—The ferro-manganese used for the present calculations contains 80 per cent. Mn, 6·5 per cent. carbon, and about 1·25 per cent. of silicon. The amount of manganese required in the finished steel is 0·75 per cent. to 0·8 per cent. Allowing for a loss of 20 per cent. to 25 per cent. of manganese when adding it to the ladle solid, the ferro-manganese required in the charge is as follows :—

Let x = percentage of manganese required. Then allowing for a 20 per cent. loss—

$$0{\cdot}75 = \tfrac{80}{100}x,$$
$$\therefore x = 0{\cdot}937\ \%.$$

Assuming that the cupola metal required will add 0·05 per cent. of manganese to the charge, then nett manganese percentage $= 0{\cdot}937 - 0{\cdot}05 = 0{\cdot}887\ \%$.

$$\therefore \text{Weight of ferro-manganese required} = \frac{43 \text{ cwts.} \times 112 \times 0{\cdot}887}{80}$$
$$= 53 \text{ lbs. approximately.}$$

The carbon added to the charge through the ferro-manganese

$$= \frac{53 \times 6{\cdot}5}{43 \times 112} = 0{\cdot}072\ \%.$$

The carbon present in the blown metal = 0·10 %,

$$\therefore \text{Carbon required to be added by cupola metal}$$
$$= \text{carbon in finished steel} - (0{\cdot}10 + 0{\cdot}072)$$
$$= 0{\cdot}4 - 0{\cdot}172 = 0{\cdot}228\ \%,$$
$$\therefore \text{Cupola metal required} = \frac{43 \times 112 \times 0{\cdot}228}{3{\cdot}4} = 323 \text{ lbs.}$$

As the cupola metal contains 0·7 % of manganese, the above 323 lbs. will add to the charge the following percentage:—

$$\frac{323 \times 0{\cdot}7}{43 \times 112} = 0{\cdot}047\ \% \text{ of manganese.}$$

In calculating the amount of ferro-manganese required, an allowance of 0·05 per cent. was deducted from the total percentage wanted in the finished steel. The above gain of 0·047 per cent. balances approximately the amount deducted.

Ferro-silicon required.—The silicon required in the finished steel is from 0·3 per cent. to 0·4 per cent. The silicon added through the ferro-manganese may be neglected, as it is so small. The silicon added to the charge through the cupola metal is as follows:—

$$\frac{323 \times 2{\cdot}0}{43 \times 112} = 0{\cdot}134\ \%.$$

The silicon required from the ferro-silicon added therefore

$$= 0{\cdot}35 - 0{\cdot}134 = 0{\cdot}216\ \%.$$

Using ferro-silicon containing 75 per cent. silicon, the following weight is required to give the additional 0·214 per cent. to the charge:—

$$\frac{43 \times 112 \times 0{\cdot}216}{75} = 13\tfrac{3}{4} \text{ lbs.}$$

The total additions, therefore, to a 2-ton charge of blown metal containing 0·1 per cent. of carbon, and traces only of silicon and manganese, to produce a steel having the following analysis: C, 0·4 per cent.; Si, 0·35 per cent.; Mn, 0·75 per cent. are—

Cupola metal	323 lbs.
Ferro-manganese (80 %) . .	53 lbs.
Ferro-silicon (75 %) . . .	$13\frac{3}{4}$ lbs.
Calcium silicide	2 lbs.
Aluminium	1 lb.

The calcium silicide and aluminium are added to the ladle while the metal is being poured from the converter, and have a very subduing effect upon it.

From the foregoing calculations it is obvious that the time required to find the additions for different kinds of steel would be considerable, particularly where the charges vary in weight. The following tables give the additions necessary to produce steels of the analyses given in Table LXII, page 245, when the charges vary in weight from 35 to 45 cwts. These classes of steel cover most of the ordinary steel foundry requirements.

TABLES OF PHYSICS

TABLE LXVII

PHYSICS TO PRODUCE STEEL HAVING THE FOLLOWING ANALYSIS: CARBON, 0·4 TO 0·45%; SILICON, 0·3 TO 0·4%; MANGANESE, 0·75 TO 0·8%. SUITABLE FOR ORDINARY CASTINGS

Weight of charge of blown metal.	Weight of cupola metal and ferro-alloys added to charge.				
	Cupola metal, containing C 3·4% Si 2·0% Mn 0·7%	Ferro-manganese, containing Mn 80·0% C 6·5% Si 1·25%	Ferro-silicon, containing Si 75·0% C 0·5%	Calcium silicide.	Aluminium.
cwts.	lbs.	lbs.	lbs.	lbs.	lbs.
35	289	46·5	11·25	1·75	1
36	297	48·0	11·5	1·75	1
37	305	49·5	11·75	1·75	1
38	313	50·75	12·0	2·0	1
39	322	52·25	12·5	2·0	1
40	330	53·5	12·75	2·0	1
41	338	54·75	13·0	2·0	1
42	346	56·25	13·5	2·0	1
43	355	57·75	13·75	2·25	1
44	363	59·0	14·0	2·25	1
45	371	60·5	14·25	2·25	1

TABLE LXVIII

PHYSICS TO PRODUCE STEEL HAVING THE FOLLOWING ANALYSIS: CARBON, 0·3 TO 0·35%; SILICON, 0·5 TO 0·6%; MANGANESE, 0·8 TO 0·9%. SUITABLE FOR CASTINGS TO BE MACHINED

Weight of charge of blown metal.	Weight of cupola metal and ferro-alloys added to charge.				
	Cupola metal, containing C 3·4% Si 2·0% Mn 0·7%	Ferro-manganese, containing Mn 80·0% C 6·5% Si 1·25%	Ferro-silicon, containing Si 75·0% C 0·5%	Calcium silicide.	Aluminium.
cwts.	lbs.	lbs.	lbs.	lbs.	lbs.
35	179	50·75	24·5	1·75	1
36	184	52·25	25·25	1·75	1
37	189	53·75	26·0	1·75	1
38	194	55·0	26·5	2·0	1
39	199	56·5	27·25	2·0	1
40	204	58·0	28·0	2·0	1
41	209	59·5	28·75	2·0	1
42	214	61·0	29·5	2·0	1
43	219	62·25	30·0	2·25	1
44	224	63·75	30·75	2·25	1
45	229	65·25	31·5	2·25	1

TABLE LXIX

PHYSICS TO PRODUCE STEEL HAVING THE FOLLOWING ANALYSIS: CARBON, 0·65 TO 0·75%; SILICON, 0·4 TO 0·5%; MN, 0·7 TO 0·8%. SUITABLE FOR LIGHT GEARING CASTINGS

Weight of charge of blown metal.	Weight of cupola metal and ferro-alloys added to the charge.				
	Cupola metal, containing C 3·4% Si 2·0% Mn 0·7%	Ferro-manganese, containing Mn 80·0% C 6·5% Si 1·25%	Ferro-silicon, containing Si 75·0% C 0·5%	Calcium silicide.	Aluminium.
cwts.	lbs.	lbs.	lbs.	lbs.	lbs.
35	656	42·5	8·75	1·75	1
36	675	43·75	9·0	1·75	1
37	694	44·75	9·25	1·75	1
38	712	46·0	9·5	2·0	1
39	731	47·25	9·75	2·0	1
40	750	48·5	10·0	2·0	1
41	769	49·75	10·25	2·0	1
42	787	51·0	10·5	2·0	1
43	806	52·0	10·75	2·25	1
44	825	53·25	11·0	2·25	1
45	844	54·5	11·25	2·25	1

TABLE LXX

PHYSICS TO PRODUCE STEEL HAVING THE FOLLOWING ANALYSIS: CARBON, 0·35 TO 0·45%; SILICON, 0·2 TO 0·3%; MANGANESE, 0·7 TO 0·8%. SUITABLE FOR HEAVY GEARING CASTINGS

Weight of charge of blown metal.	Weight of cupola metal and ferro-alloys added to the charge.				
	Cupola metal, containing C 3·4% Si 2·0% Mn 0·7%	Ferro-manganese, containing Mn 80·0% C 6·5% Si 1·25%	Ferro-silicon, containing Si 75·0% C 0·5%	Calcium silicide.	Aluminium.
cwts.	lbs.	lbs.	lbs.	lbs.	lbs.
35	227	43·75	6·25	1·75	1
36	234	45·0	6·25	1·75	1
37	240	46·25	6·5	1·75	1
38	247	47·5	6·75	2·0	1
39	253	48·75	6·75	2·0	1
40	260	50·0	7·0	2·0	1
41	266	51·25	7·25	2·0	1
42	273	52·5	7·25	2·0	1
43	279	53·75	7·5	2·25	1
44	286	55·0	7·75	2·25	1
45	292	56·25	7·75	2·25	1

TABLE LXXI

PHYSICS TO PRODUCE STEEL HAVING THE FOLLOWING ANALYSIS: CARBON, 1·0 TO 1·25%; SILICON, 0·2 TO 0·3%; MANGANESE, 10·0 TO 12·0%. SUITABLE FOR CASTINGS SUBJECTED TO GREAT WEAR. MANGANESE STEEL.

Weight of charge of blown metal.	Weight of cupola metal and ferro-alloys added to charge.				
	Cupola metal, containing C 3·4% Si 2·0% Mn 0·7%	Ferro-manganese, containing Mn 80·0% C 6·5% Si 1·25%	Ferro-silicon, containing Si 75·0% C 0·5%	Calcium silicide.	Aluminium.
cwts.	lbs.	lbs.	lbs.	lbs.	lbs.
35	None	787	None	None	None
36	,,	810	,,	,,	,,
37	,,	832	,,	,,	,,
38	,,	855	,,	,,	,,
39	,,	877	,,	,,	,,
40	,,	900	,,	,,	,,
41	,,	922	,,	,,	,,
42	,,	945	,,	,,	,,
43	,,	967	,,	,,	,,
44	,,	990	,,	,,	,,
45	,,	1012	,,	,,	,,

TABLE LXXII

PHYSICS TO PRODUCE STEEL HAVING THE FOLLOWING ANALYSIS: CARBON, 0·7 TO 0·8%; SILICON, 0·4 TO 0·5%; MANGANESE, 0·75 TO 0·85%; CHROMIUM, 0·5 TO 1·0%. SUITABLE FOR CASTINGS SUBJECTED TO WEAR. CHROME STEEL

Weight of charge of blown metal.	Weight of cupola metal and ferro-alloys added to charge.					
	Cupola metal, containing C 3·4% Si 2·0% Mn 0·7%	Ferro-manganese, containing Mn 80·0% C 6·5% Si 1·25%	Ferro-silicon, containing Si 75·0% C 0·5%	Ferro-chrome, containing Cr 60·0% C 0·5%	Calcium silicide.	Aluminium.
cwts.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
35	787	48·0	5·25	40·25	1	0·5
36	810	49·5	5·5	41·5	1	0·5
37	832	50·75	5·5	42·5	1	0·5
38	855	52·25	5·75	43·75	1	0·5
39	877	53·5	5·75	44·75	1	0·5
40	900	55·0	6·0	46·0	1	0·5
41	922	56·5	6·25	47·25	1	0·5
42	945	57·75	6·25	48·25	1	0·5
43	967	59·25	6·5	49·5	1	0·5
44	990	60·75	6·5	50·5	1	0·5
45	1012	62·0	6·75	51·75	1	0·5

TABLE LXXIII

Physics to produce Steel having the following Analysis: Carbon, 0·4 to 0·6%; Silicon, 0·4 to 0·6%; Manganese, 0·8 to 0·9%. Suitable for Castings subjected to Pressure, such as Hydraulic Cylinders, etc.

Weight of charge of blown metal.	Weight of cupola metals and ferro-alloys added to the charge.				
	Cupola metal, containing C 3·4% Si 2·0% Mn 0·7%	Ferro-manganese, containing Mn 80·0% C 6·5% Si 1·25%	Ferro-silicon, containing Si 75·0% C 0·5%	Calcium silicide.	Aluminium.
cwts.	lbs.	lbs.	lbs.	lbs.	lbs.
35	297	50·75	15·0	1·75	1
36	306	52·25	15·25	1·75	1
37	314	53·5	15·75	1·75	1
38	323	55·0	16·25	2·0	1
39	331	56·5	16·5	2·0	1
40	340	58·0	17·0	2·0	1
41	348	59·5	17·5	2·0	1
42	357	61·0	17·75	2·0	1
43	365	62·25	18·25	2·25	1
44	374	63·75	18·75	2·25	1
45	382	65·25	19·0	2·25	1

TABLE LXXIV

Physics to produce Steel having the following Analysis: Carbon, 0·1 to 0·2%; Silicon, 0·1 to 0·3%; Manganese, 0·2 to 0·4%. Suitable for Castings for Electrical Work. Magnet Steel

Weight of charge of blown metal.	Weight of cupola metal and ferro-alloys added to the charge.				
	Cupola metal, containing C 3·4% Si 2·0% Mn 0·7%	Ferro-manganese, containing Mn 80·0% C 6·5% Si 1·25%	Ferro-silicon, containing Si 75·0% C 0·5%	Calcium silicide.	Aluminium.
cwts.	lbs.	lbs.	lbs.	lbs.	lbs.
35	None	15·0	None	5·25	6·25
36	,,	15·5	,,	5·5	6·25
37	,,	15·75	,,	5·5	6·5
38	,,	16·25	,,	5·75	6·75
39	,,	16·5	,,	5·75	6·75
40	,,	17·0	,,	6·0	7·0
41	,,	17·5	,,	6·25	7·25
42	,,	17·75	,,	6·25	7·25
43	,,	18·25	,,	6·5	7·5
44	,,	18·75	,,	6·5	7·75
45	,,	19·0	,,	6·75	7·75

TABLE LXXV

PHYSICS TO PRODUCE STEEL HAVING THE FOLLOWING ANALYSIS: CARBON, 0·35 %; SILICON, 0·4 TO 0·45 %; MANGANESE, 0·75 TO 0·85 %. SUITABLE FOR CASTINGS WITH BEARING SURFACES, AND TO GIVE A TENACITY OF 35 TONS PER SQUARE INCH WITH 10 % ELONGATION ON 2″

Weight of charge of blown metal.	Weight of cupola metal and ferro-alloys added to the charge.				
	Cupola metal, containing C 3·4% Si 2·0% Mn 0·7%	Ferro-manganese, containing Mn 80·0% C 6·5% Si 1·25%	Ferro-silicon, containing Si 75·0% C 0·5%	Calcium silicide.	Aluminium.
cwts.	lbs.	lbs.	lbs.	lbs.	lbs.
35	220	48·25	17·5	1·75	1
36	227	49·5	18·0	1·75	1
37	233	51·0	18·5	1·75	1
38	239	52·25	19·0	2·0	1
39	245	53·75	19·5	2·0	1
40	252	54·0	20·0	2·0	1
41	258	55·25	20·5	2·0	1
42	265	56·75	21·0	2·0	1
43	271	58·0	21·5	2·25	1
44	277	59·5	22·0	2·25	1
45	283	60·75	22·5	2·25	1

TABLE LXXVI

PHYSICS TO PRODUCE STEEL HAVING THE FOLLOWING ANALYSIS: CARBON, 0·2 TO 0·25 %; SILICON, 0·2 TO 0·25 %; MANGANESE, 0·5 TO 0·6 %. SUITABLE FOR CASTINGS FOR LOCOMOTIVE AND SIMILAR WORK. CENTRE STEEL

Weight of charge of blown metal.	Weight of cupola metal and ferro-alloys added to charge.				
	Cupola metal, containing C 3·4% Si 2·0% Mn 0·7%	Ferro-manganese, containing Mn 80·0% C 6·5% Si 1·25%	Ferro-silicon, containing Si 75·0% C 0·5%	Calcium silicide.	Aluminium.
cwts.	lbs.	lbs.	lbs.	lbs.	lbs.
35	70	31·5	8·75	1·75	1·75
36	72	32·5	9·0	1·75	1·75
37	74	33·25	9·25	1·75	1·75
38	76	34·25	9·5	2·0	2·0
39	78	35·0	9·75	2·0	2·0
40	80	36·0	10·0	2·0	2·0
41	82	37·0	10·25	2·0	2·0
42	84	37·75	10·5	2·0	2·0
43	86	38·75	10·75	2·25	2·25
44	88	39·5	11·0	2·25	2·25
45	90	40·5	11·25	2·25	2·25

PART III

THE OPEN-HEARTH PROCESS

CHAPTER XXIV

THE ACID PROCESS

THE name "acid" is given to the various processes of steel manufacture carried out in the open-hearth furnace, when the operations of melting and converting are conducted upon a sand hearth. When cold charges are used, the process consists of melting and converting into steel the materials upon the hearth by the action of heat from the fuel used, with suitable reducing oxides such as ore and mill scale when necessary, and by the additions of reagents. When liquid pig is used as part of the charge, the process is principally one of converting only. Scrap steel which is added, has, of course, to be melted either in the liquid bath or by the action of the flame.

Various proportions of pig iron and scrap steel are employed to make up the charges in what is known as the "Martin Process"; the same may be said also of the pig and ore process. Between the extremes of high and low proportions of pig iron in charges for both processes, a variety of compositions exist, some of which are given in Chapter XXXVI.

Method of Conducting the Process. Preparing the Furnace for the Charge.—To start a newly-erected furnace and its equipment, very great care is required in drying the brickwork throughout the whole structure. If hastily heated, much trouble will be experienced, due to the expansion of the silica brickwork. If during the building of the flues, regenerators, and furnace, the weather has been dry, a good deal of the brickwork will have dried naturally before the work is completed. In any case it is advisable to allow the furnace to remain for several days with the furnace doors wide open and all valves and dampers open to the chimney, so that natural drying may proceed freely before any fires are lighted in the furnace. A coke fire at the base of the chimney will promote a better current of air throughout the system and will help the gradual drying of the chimney. After natural drying has been continued for some days, coke fires are placed in each of the regenerator chambers and at different places in the flues. These are increased in size gradually, care being taken that tie bolt nuts are liberated to meet the expanding brickwork. After 3 to 6 days' firing in this way (the length of time varying according to the size of the furnace and length of the flues), fires are placed in the furnace hearth near to the ports in the first place and then in the centre of the hearth, so that the hearth may get thoroughly heated before the gas is allowed to enter the furnace. When all the brickwork throughout the structure and flues is well dried, the chequer bricks are built into the regenerator chambers and the furnace bottom made. The latter is done by gradually fritting the surface of the brickwork and fusing silver sand in thin layers on the bottom until the necessary

thickness is obtained. The gas from the producers (or oil, if liquid fuel is used) is turned on before making the sand bottom.

Admission of Gas to the Furnace.—Care must be taken to prevent any residual air in the gas flues from mixing with the gas from the producer in such proportions as would cause an explosion when the mixture is lighted. The first precaution is to dry the flue thoroughly, and then to expel the air from the flue by causing the gas to issue through the manhole nearest to the furnace for some time before turning it into the furnace. This is usually an effective means of driving the air from the flues. In addition to these precautions it is advisable to test the lighting value of the gas as it issues from the manhole cover before lighting it in the furnace; even then the lighting in the furnace is commonly accompanied with a report. While this is being done, all air from the reversing valves is excluded, the gas burning limply in the furnace hearth until the air from the regenerators mixes with the gas, producing gradually the usual intense heat in the furnace.

Before any charge is introduced, the furnace temperature is brought up to a very high degree. The tap-hole is then formed, and the furnace prepared to receive the charge.

Charging the Materials. Charging by Hand.—Where solid charges are used, charging by hand is still a very common practice in works using furnaces up to 25 tons, and in some works in England furnaces of 50 tons capacity are charged by hand. Needless to say, the time in charging 50 tons of cold material by hand is considerable, the first part of the charge being melted two or three hours before the final instalments are made. The average time taken to charge a 25-ton furnace in English works is from 7½ to 8 hours, when half the charge consists of pig iron and the remainder is scrap.

Charging by hand is done with long bars flattened at the charging end to carry pig and scrap into the furnace. In small furnaces where no overhead crane or swing jib crane is used, a roller is fixed to the door ledge of the furnace and over the roller, the bar is pushed by one or two men and the material landed on the sand bottom of the furnace. Where a crane is available, the charging is done more rapidly; heavy lumps of scrap can be picked up by the crane, placed on the "peel" or charging bar, and after being suspended by the crane, the bar is pushed into the furnace by hand and the scrap tipped on to the hearth.

Charging by Machine.—In modern plants, furnaces of 25 tons and upwards are usually equipped with machines. The materials composing the charge are picked up from the stockyard by an overhead electric crane carrying a magnet, and the charging pans arranged on trucks are filled with scrap and pig iron in the proportions determined by the steel superintendent, the pig and scrap being kept in separate pans. These pans are then drawn by a steam loco and passed over the weighbridge to record the weight before being pushed on to the charging stage of the furnace alongside the furnace doors. The arm of the charger engages with the pan on the truck, lifting it and carrying it to the furnace door, then going forward and tipping the contents upon the hearth. The pan is withdrawn and placed upon the empty truck, which is pushed along past the furnace. A total charge of 50 tons can be charged in this way in about 20 minutes.

It is not merely the saving in time that is effected by mechanical charging, but loss of furnace heat is avoided also, as the doors do not require to be opened so frequently as in hand charging. We witnessed, in 1911, several modern open-hearth furnaces, designed by Messrs. Paul Schmidt and Desgraz, charged with an electric charger in a large German steelworks. The complete charge was put into the furnace in the manner already described, and five heats obtained every 24 hours. The Martin pig and scrap process was conducted, and the charge was composed of selected scrap and pig, so that no refining was required. It would

take longer in some works where hand charging is done, to do the charging alone, than it takes in the works in question to make the steel into ingots.

Charging Partly Liquid Charges.—The charging of liquid metal and solid scrap hastens the operation of melting and conversion. The solid scrap is handled as previously described, but the liquid iron is taken from the mixer in a ladle truck, the contents of which are tipped by crane or hydraulic tipper into a carriage chute which carries the metal into the furnace. The truck of metal passes over the weighbridge, and the weight is recorded before being taken to the furnace.

A more common method of conveying the metal from the mixer to the furnace is to carry the ladle of metal from the mixer by an overhead crane and tip the contents by an auxiliary crane into a carriage chute, and from thence to the furnace.

The time taken in charging liquid metal is less than that required for charging solid pig iron, and the time occupied in converting the charge into steel is shortened also. The composition of different charges and the analyses of the pig iron used, are given in Chapter XXXVI. It is, therefore, not intended to repeat these here.

Operation of the Furnace during Melting and Converting.—The process of melting cold charges is very slow. Compositions consisting of large percentages of low carbon scrap and small amounts of pig iron, take longer to melt than charges with larger proportions of pig iron. The pig iron usually melts first, being fusible at a lower temperature than the mild steel scrap. If too little pig iron be used in the charge oxide of iron will be formed, and the lining of the furnace will suffer. To rectify this, additions of pig iron are necessary. Sometimes coal is added with the charge in the first place to make up for the small proportion of pig iron used. An excess of pig iron in the initial charge can be rectified by the flame or additions of ore, and as a rule it is safer to use a sufficiency of pig iron in the first place.

The melter regulates the gas and air supply in the proportions most suited to the melting requirements. Soon after the charge is molten, the ebullition of gas through the coating of slag upon the surface of the metal shows clearly that carbon is being liberated from the bath. During the melting the oxidation of carbon has been proceeding slowly, but is now active, ore being added when it is found advisable to accelerate the removal of the carbon. The appearance of the "boil," which is unmistakable by the rapid ebullition of gas from the surface, comes on from 1 to 3 hours after melting, depending upon the temperature and condition of the metal, and lasts 1, 2, or 3 hours, after which the charge is tapped. The "boil" is sometimes held back by the melter if the carbon is being removed too rapidly, and the phosphorus and sulphur remain in too large proportions.

Other elements such as silicon and manganese are removed from the metal to the slag during the melting. The progress of the chemical action is not merely judged by the appearance of the bath, but by the frequent tests taken from the charge after the metal is melted and during the "boil."

Examination of Tests.—Two kinds of tests are usually made :—

1. Fracture tests.
2. Chemical tests.

A sample is generally taken from the bath when the metal is melted, and before any "opening out" of the slag is caused by the use of iron oxides. The exact state of the metal when melted can be fairly gauged by fracture and analysis tests, and these guide the melter in finishing the steel. The most troublesome elements in the charge are the phosphorus and sulphur when present in the raw materials in objectionable proportions, and although much

has been done by workers such as Stead, Arnold, Saniter, and others in simplifying the removal of these elements, much still remains to be done.

The improvements in the methods of making rapid and accurate tests in the charging stage laboratory, have made it possible to estimate the carbon, phosphorus, and sulphur contents in a charge sample in from 10 to 12 minutes, and if manganese is estimated, 5 minutes longer is taken. Messrs. Harrison & Wheeler in their valuable research,[1] give examples of such tests, which are perhaps found most useful in the basic process where phosphoric pig irons are used.

With reference to the removal of sulphur from iron and steel, Mr. Donald M. Levy sums up his investigations as follows:—[2]

"The separation of manganese sulphide both in irons and steels is thus largely dependent upon:—

(*a*) Condition and resulting properties of the sulphide.
(*b*) Composition and resulting properties of the metal.
(*c*) Temperature of the metal.
(*d*) Solubility of the sulphide in solid and liquid metal.
(*e*) The mechanical and physical conditions.
(*f*) Influence of the slag and of oxidising conditions.

Some of these are interdependent, but a systematic investigation of these factors, together with an understanding of their bearing on the thermal, physical, and chemical equilibrium of the systems, is the key to the successful elimination of the sulphur from the metals in practice, or to so controlling its condition and distribution as to convert it to its least harmful form."

Prof. Arnold, many years ago, pointed out that sulphur in steel in the form of manganese sulphide was not dangerous.

Chemical Reactions in the Acid Open-hearth Process.—The removal of metalloids during the process of melting and converting a charge of pig iron, scrap steel, and ore to steel, is the result of chemical action by oxidation, and is an interesting study. This action is promoted by the heat of the flame, and assisted by its oxidising influence. The rate of chemical action is dependent among other things upon the nature of the charge, the condition of the bath, the intensity of the flame, and the manipulation of the furnace.

To trace the results of any one charge in the furnace does not afford such comprehensive and reliable evidence of what actually takes place as when the average results from groups of charges are taken. This fact was pointed out by Mr. H. H. Campbell, and the following results, given by him,[3] may be taken as representing the history of the progress of the average mild steel charge in the acid open-hearth process. The results under Group I. show an average of 19 boiler plate heats of steel, producer gas being used as the heating agent. Under Group II. are given the results of 6 boiler plate heats of steel, oil gas under steam pressure being used as the heating agent.

	Materials used	Group I.	Group II.
1.	Pig iron, Si, 1·72%; C, 3·5% . . .	11,700 lbs.	20,700 lbs.
2.	Steel scrap { Rail steel, Si, 0·07%; C, 0·40% .	39,580 ,,	29,600 ,,
	Boiler plate, Si, 0·02%; C, 0·13%	5,970 ,,	7,200 ,,
3.	Ore, FeO, 81%; free O, 9%	1,020 ,,	850 ,,

[1] "Journal Iron and Steel Institute," 1908, III, p. 272.
[2] *Ibid.*, 1911, III, p. 311.
[3] "Transactions American Inst. of Mining Engineers," vol. 19, p. 160.

Analyses of Charge and Slags

	Si %	Mn %	C %	Si %	Mn %	C %
4. Metal when melted	0·02	0·09	0·54	0·05	0·06	0·64
5. Metal before tapping	0·02	0·04	0·13	0·01	0·02	0·12
	SiO_2 %	MnO %	FeO %	SiO_2 %	MnO %	FeO %
6. Slag after melting	50·24	21·67	23·91	49·46	13·16	33·27
7. Slag before tapping	49·4	16·50	29·5	49·36	11·30	34·11
8. Time of melting	433 minutes			480 minutes		
9. Time of oreing	150 ,,			120 ,,		
10. Weight of slag in ladle	4050 lbs.			5670 lbs.		
11. Weight of slag before tapping (assumed)	3900 ,,			5520 ,,		
12. Weight of MnO in slag before tapping (from items 7 and 11)	644 ,,			624 ,,		
13. Weight of MnO formed after melting (from items 4 and 5)	36 ,,			28 ,,		
14. Amount of MnO in slag after melting	608 ,,			596 ,,		
15. Percentage of MnO in slag after melting (see item 6)	21·67			13·16		
16. Weight of slag after melting (from items 14 and 15)	2810 lbs.			4530 lbs.		

From the foregoing analyses and weights, the progress of the oxidation can be followed. Mr. Campbell calculated the weight of the slags formed after melting the charge and before adding the ore, from the amount of MnO in the slags. His method of determination was based upon the fact that all the MnO must come from the Mn in the materials of which the charge is composed, and knowing the weights and analyses of the charges, as well as the analyses of the slags at the different periods, he was able to ascertain the weight of the slags with reasonable approximation.

The chemical reactions of other kinds of charges in the acid furnace are analogous, and can be investigated on similar lines from the weights and analyses of the slags produced. It is, therefore, unnecessary to give other illustrations, which can be multiplied in everyday practice.

CHAPTER XXV

THE BASIC OPEN-HEARTH PROCESS

The basic open-hearth process differs from the acid open-hearth process chiefly in the nature of the chemical reactions which occur during the heat, and not in the general principle which applies to both, namely, the oxidation of impurities in the charge and their removal through the slags and gases. The difference in the chemical reactions is due to the presence of phosphorus and sulphur in excess of that in the iron suitable for the acid open-hearth process, and principally in the former element. Chemically considered they are both acids, and have a greater affinity for iron when at a high temperature than for the oxygen in the atmosphere. They cannot, therefore, be oxidised like carbon, silicon, and manganese under the influence of the oxidising flame in the furnace only. When oxidised, phosphorus and sulphur form acid compounds, but this only takes place when they are exposed at a high heat to the action of lime, or some other active mineral base with a stronger affinity for them than they have for iron.

As the use of lime in an acid-lined furnace, as a reducing agent, would flux and destroy the lining, it is necessary to have a non-acid lining, or what is known as a basic lining, to allow of the reactions taking place without much wear of the lining. The various kinds of basic materials used for open-hearth furnace linings are discussed and described in Chapter II, Section III, on "Refractory Materials." They consist as a rule of dolomite or magnesite, but other materials are used also.

The general design of fixed open-hearth furnaces used in both the acid and basic processes is the same, although in certain dimensions they differ. The basic-lined furnace hearths are made larger than acid-lined furnaces of the same nominal capacity, to permit of supplies of lime and ore and other oxides being added.

Various Open-hearth Furnace Processes.—Processes which are generally known as the "pig and scrap," the "pig, scrap, and ore," the "pig and ore," and the "scrap and carbon," are common to both the acid and basic open-hearth processes. Most of the above processes were carried out originally in fixed open-hearth furnaces with cold metal charges, and a large proportion of the steelworks to-day employ the fixed open-hearth furnace in preference to the tilting furnace.

The Basic Open-hearth Fixed Furnace.—The method employed in the fixed furnace practice, when cold charges are used, depends largely upon local conditions. If pig iron is cheaper than scrap, only the suitable scrap steel and iron made in the works are used again in the charges, with additions of ore, lime, and scale to produce the necessary reactions. If scrap abounds and is found more economical for use than pig iron, very large percentages are employed, with additions of coal, if necessary, to supply extra carbon to the charge. Where the use of pig iron is prohibitive by reason of price, the scrap and carbon process, such as proposed by Leopold Pszczolka of Graz,[1] might be

[1] Dichmann, "Basic Open-hearth Steel," p. 253.

employed. The most common practice is to use pig iron, scrap steel and iron, and oxides, in proportions which will produce the steel required in the most rapid manner and at least cost.

The progress of the operation of a typical charge in the fixed open-hearth furnace may be described as follows. After the furnace bottom has been repaired with dolomite mixed with tar, or with dry dolomite for drying up holes, the furnace is charged by hand or machine charged. The hand-charging of even a 25-ton furnace takes a long time, several hours elapsing before the materials are completely deposited in the furnace. This practice of prolonging the time of charging varies at different works. Lime and metalliferous slag are added with the charge, sometimes before the cold pig iron, at other times during the progress of the additions of pig iron and scrap. Small amounts of coal are added usually after the pig iron and before the scrap, when low percentages of pig iron are used in the charge. Sometimes the charging will continue, when done by hand, for 9 or 10 hours, the melting proceeding meanwhile and the entire charge being melted in about 1 to 2 hours after the charging is completed. A melting sample is taken to ascertain the condition of the metal in the bath, after which additions of oxides are made according to the rate of oxidation it is desired to promote. In about 1 hour after the metal is melted, the boil commences and the refining proceeds, the carbon and other elements being reduced as required. This may be done by removing practically all the carbon present and adding the required amount afterwards, or by arresting the oxidation of the original carbon in the metal at the point desired.

The silicon and manganese are readily removed by the oxidising influence of the flame. Additions of ferro-manganese, and sometimes ferro-silicon, have to be made to the steel as a rule when the heat is finished or as the steel is being tapped into the ladle, to bring it to the standard required.

The elimination of phosphorus and sulphur presents the greatest difficulty. If the phosphorus approaches 0·1 per cent. and the sulphur is still high, say about the same percentage, both can be reduced with additions of fluorspar and lime, about twice the amount of the former being used. If, however, the phosphorus is low, say about 0·04 per cent., and it is desired to remove the sulphur, the addition of fluorspar will not produce satisfactory results, and the heat will become difficult to control. Hence the necessity of careful tests for phosphorus and sulphur during the finishing stages of the heat, to avoid troublesome and wild metal.

The time required to complete a heat from the start of the boil varies according to the materials in the charge, etc., but as a rule from 1 to 3 hours are taken to finish the heat.

Molten Metal Basic Open-hearth Processes

For many years past molten metal charges, both in part and as a whole, have been employed in the basic open-hearth furnace. The important economy in utilising the initial heat of the blast furnace metal, and thereby accelerating the reactions in the open-hearth furnace, shortening the duration of the heat, increasing the output, and reducing the fuel consumption, indicate an immense gain to be derived from molten metal charges.

Many difficulties, however, had to be overcome and modifications made in the working of the molten charges, before successful and rapid steel manufacture became an accomplished fact. Much disappointment was also experienced by many of those employed in trying to overcome the difficulties. What appeared on the surface a very economical method proved, under some conditions, more costly than the ordinary pig and scrap process. With molten metal the lining of

the furnace was frequently damaged, holes being made in the bottom, while the banks and walls were scoured by the cutting action of the oxides, which, of necessity, were required in excess to reduce the elements in a charge wholly of pig iron, thus producing an unwieldy amount of slag, which frequently overflowed the banks and ports, escaping through the doorways and also into the regenerators before it could be removed.

These difficulties, as well as that of removing the slags from the fixed furnace, led to the introduction of the tilting open-hearth furnace, which made the removal of the slag a very simple operation. The bottom and walls of the furnace were not so subject to deterioration, seeing that the metal in the bath could be moved from time to time during the operation. This development, which was made possible by the use of the Wellman Tilting Furnace, and subsequently modified and improved by the Campbell Tilting Furnace, was a distinct advantage in working the process.

Campbell,[1] writing on the advantages of his furnace, says that nowhere else has iron been worked directly from the blast furnace without the use of a receiver, with silicon varying from 0·5 up to 3·0 per cent., and with no prohibitory trouble from frothing or from loss of time. This trouble is avoided by the ability to tip the furnace and prevent the metal and slag from flowing out of the door on the front side, there being no door on the tap hole side, the excess of slag being provided for by holes left in the bottom of the port opening. While it was possible at Steelton Steel Works, Pennsylvania, to use pig iron from the blast furnace with such varying silicon contents because of the ease of manipulation of the Campbell Tilting Furnace, yet in other steel works one of the chief hindrances to the success of many of the molten metal charges in the basic open-hearth furnace was due to the irregularity of the composition of the metal from the blast furnace.

Since the introduction of the mixer in 1889, a most distinct advance in the rapid development of steel manufacture has been made. At first it was principally used as a collector of iron from the blast furnace, giving uniformity in the composition of the basic iron supplied to the furnace. The mixer, however, has long since proved to be more than a collector of metal for easy distribution, and has taken the place of a preliminary refiner of the metal in many works, at the same time raising the temperature of the basic iron before it reaches the open-hearth furnace.

Some mixers are more like huge tilting furnaces, with all the heating and regenerating equipment of the ordinary modern open-hearth furnace, and play the part of intermediate furnaces for considerably reducing the manganese, silicon, phosphorus, and sulphur from the metal before it is taken to the basic open-hearth furnaces for final refining. Other mixers are simply used as collectors and desulphurisers, supplying metal of uniform composition and temperature to meet the conditions required.

For both the Bessemer and open-hearth processes, the mixer has been of very great value (See Chapter XXX for illustrations and descriptions of mixers). The mixer has been, in some measure, the supplanter of the Bessemer converter, and like furnaces, as far as their association with open-hearth furnaces as preliminary refiners is concerned. What have been long known as duplex processes in steel making, are still conducted in the U.S.A., Canada, Mexico, and Japan (although apparently abandoned on the Continent[2]). These had for their object the partial refinement of otherwise troublesome elements, the presence of which in the basic open-hearth furnace would have made the process impossible in some cases. Then, again, the rapidity of output was

[1] Campbell, "Metallurgy of Iron and Steel," p. 142.
[2] "Iron and Coal Trades' Review," 1910, p. 88.

another special feature. These functions can be performed now, to some extent, by the mixer.

As long ago as 1878,[1] at Witkowitz, the Bessemer converter was used for refining the metal before passing it on to the open-hearth basic furnace, and since then it has been employed in several works. In America it is used in the works of Jones and Laughlin, Pittsburg, and the Dominion Iron and Steel Co., Sydney, Nova Scotia,[2] as well as in other notable works in conjunction with the basic open-hearth furnace.

Other combinations of furnaces are now used, such as the basic open-hearth and electric furnace. Among other users of this combination are the American Steel and Wire Co., Worcester, Mass., U.S.A. A Bessemer electric furnace has also been introduced by Verdon Cutts and Hoult of Sheffield, which has for its object the rapid production of steel without transferring the blown metal to another furnace; no results of actual steel made from this process appear to have been published.

Many modifications and combinations of furnaces have been introduced to accelerate the production of steel, and with the object of using various grades of pig iron, not always distinctly basic or acid iron. Among the many processes which are principally adapted for the use of molten metal charges are the following: The Witkowitz, Pszczolka-Daelen, Bertrand-Thiel or Hoesch, Talbot Continuous, Monell and Rees-James, and others.

The distinctive features of each of these processes may be briefly summarised as follows:—

The Witkowitz Duplex Process.—This process consists of converting iron into steel which contains too much phosphorus for the acid and too little for the basic Bessemer process. The partial deoxidation of manganese, silicon, and carbon in the acid Bessemer, and the subsequent removal of these elements, together with the phosphorus in the basic open-hearth furnace, forms the basis of the process. When the process was introduced at Witkowitz, iron containing 3·7 per cent. C; 1·2 per cent. Si; 2·7 per cent. Mn; 0·2 per cent. P; and 0·02 per cent. S, was first converted to metal containing 0·1 per cent. C and 0·4 per cent. Mn, with no reduction of phosphorus and sulphur, and was subsequently refined in the basic open hearth in the ordinary way. A charge of 10 tons was blown in the acid lined converter for about 8 minutes, and finished in the basic open-hearth furnace in about 3 hours, if no scrap or extra pig iron were added.[3]

The Pszczolka-Daelen Process.—This process is based upon the same principle as that employed at Witkowitz, and consists of the removal (in a converting vessel) of a large portion of the impurities from blast furnace metal, before the steel is finished in the open-hearth furnace. The difference in the method of carrying it out appears to have been in the use of a specially constructed ladle, into which the metal was tapped direct from the blast furnace, and from thence into the open-hearth furnace, the partial removal of the impurities being carried out before the metal was poured into the open-hearth furnace.

At Krompach, in Hungary,[4] a 10-ton fixed, box-shaped converter ladle was used, into which hot blast at a low pressure was blown through inclined tuyeres on to the surface of the metal supplied from the blast furnace. The waste in reducing the iron containing 3·5 per cent. C, 2·2 per cent. Mn, and 1·0 per cent. Si, to a carbon content of about 1·0 per cent., was about 7·29 per cent. The iron, when transferred to the basic open-hearth furnace, was finished in the usual manner. A gain in the rate of output was reckoned as equal to 7 heats in

[1] "Iron Age," vol. 76, p. 609.
[2] *Ibid.*, vol. 85, p. 1158.
[3] *Ibid.*, vol. 76, p. 609.
[4] "Journal Iron and Steel Institute," 1904, II, p. 589.

24 hours, against 6 heats in the same time of ordinary scrap metal with cold charges containing 1 per cent. of carbon. There was also a saving in fuel equal to 2 to $2\frac{1}{2}$ cwts. of coal per ton of steel output—3 cwts. of coal per ton being required in the molten process against 5 to $5\frac{1}{2}$ cwts. in the cold scrap melting.

Considerable difficulties arose in the use of the box-shaped converter, which led to other forms being tried, but it does not appear that the process has had wide application.

The Bertrand-Thiel or Hoesch Process.—The Bertrand-Thiel process dates back to 1894, when it was patented. Mr. John H. Darby and Mr. George Hatton, in writing on "Recent Developments of the Bertrand-Thiel Process in the Manufacture of Steel,"[1] state that in their opinion the basis for the use of two furnaces in the process is expressed in the words of A. Ledebur, "that if two substances react on each other chemically, this reaction proceeds more slowly the more the two substances are diluted by other substances which remain inert. In other words, the greater the excess of one of the two reacting substances the more quickly is the chemical conversion of the other completed."

In the paper referred to by Darby and Hatton, the working of the process at Brymbo, Round Oak, and at the Hoesch Works, Dortmund, is described. Since 1905, when these developments were recorded, further improvements have been made.

The original object was the removal of large accumulations of slag formed in the earlier part of the process while melting solid charges; which, if left to the end of the heat, would become very troublesome, hinder the rate of output, and impoverish the quality of the product. To carry out the process, two open-hearth fixed furnaces were employed. In one furnace the phosphoric pig iron was melted, and the bulk of the phosphorus and most of the silicon, with part of the carbon and manganese, were removed. In the second furnace, scrap steel, with suitable additions of iron ore and lime, were charged and heated before pouring into the furnace the molten metal from the first furnace. In charging the molten metal into the second furnace, care was taken to prevent slags from the first furnace being charged with the metal.

From six to seven 20-ton heats of soft steel could be produced in this way every 24 hours. At Brymbo and at the Hoesch Works, about ten 20-ton heats were produced in 24 hours. Mr. Springorum,[2] the manager of the Hoesch Works, said the iron they used contained 1·8 per cent. P, 0·3 to 0·5 per cent. Si, and 1·5 per cent. Mn, and that there was no difficulty in getting regularly 0·015 per cent. P in soft steel and 0·02 to 0·04 per cent. in hard steel. He stated also that 9 to 10 heats were obtained in 24 hours, working with fluid charges in the primary furnace. The life of the furnace was 240 charges without repairs.

The present method adopted with much success at the Hoesch Works, is that of converting to steel molten pig iron from the mixer, in two stages, with the use of one furnace. Before the fluid iron is charged into the furnace, lime, iron ore, and rolling mill scale, are placed on the bottom of the furnace hearth. Immediately the molten metal is charged, reactions commence, and phosphorus is rapidly oxidised, while the metal is at a moderately low temperature, in the presence of plenty of lime. This is one of the special features of the process. About $2\frac{1}{2}$ hours after the commencement of the heat, during which the temperature has risen considerably, and the phosphorus has been reduced to about 0·3 per cent., the whole charge is tapped into a ladle, the slag poured off, and the partly converted iron returned to the furnace, but not before more additions of lime, ore, and scrap, have been made. The charge is then finished, during

[1] "Journal Iron and Steel Institute," 1905, I, p. 122.
[2] *Ibid.*, 1905, I, p. 132.

which period additions of scale and lime are made, together with ferro-manganese, before the metal is tapped.

In Table LXXVII (p. 269), given by Dr. O. Petersen,[1] are recorded the chemical changes which take place during the progress of a typical heat by the Hoesch process.

It will be observed that in little more than one hour from the time of charging the molten iron, the phosphorus is reduced from 1·86 to 0·37 per cent., and the slag contains over 22 per cent. of phosphoric acid. During the same period the carbon is reduced about 50 per cent., while the manganese, which, at the beginning of the process, was rapidly converted to MnO, returns partly from the slag to the metal as the temperature of the bath increases and the oxidation of carbon proceeds. With reference to silicon, only traces of it remain during the first period, as it is removed at the commencement of the process.

Before the second period commences, a liberal addition of spathic ore, with scrap and lime, are charged into the furnace, the ore containing from 9 to 10 per cent. of manganese. An ore high in manganese is necessary, owing to the depleted manganese condition of the iron when returned to the furnace. The slag formed during the second period is rich in manganous oxide, and as the process proceeds an active deoxidation of the carbon takes place, particularly in the early stages of the second period. The manganese is likewise reduced from the slag during the process, forming an important deoxidiser. The removal of the phosphorus proceeds uniformly throughout the second period, and the reduction of the sulphur is about the same during each period. Other interesting facts are disclosed by an examination of the metal and slag analyses given.

With reference to the life of the furnace, the average number of charges made from one lining is 400, the bulkheads of the furnace being repaired once during the same output. The hearth lasts about 2 to 3 years, and the chequers are renewed every 600 to 800 heats.

The Talbot Process.—This process stands out distinctly from the other molten metal processes in so far that it provides a means of continuous steel making. The principle of the process is based on the rapid decarburisation of molten pig iron when charged into a bath of liquid low carbon steel of 4 to 5 times the amount of iron charged. As the temperature of the bath of metal is higher, and the carbon content much lower than that of the iron charged, the reactions proceed most vigorously between the impurities in the iron and the highly oxidised slags, formed by the large additions of lime and scale made to the bath before the molten pig iron is charged.

The process is conducted in a tilting open-hearth furnace, in which the formation and removal of slag can be manipulated easily. Furnaces up to 250 tons capacity are in constant operation, producing from 50 to 80 tons of steel every 3 to 4 hours. This process is particularly applicable to the manufacture of mild steel.

In Chapter XXXV this process is dealt with more fully.

The Talbot Continuous Process in Fixed Open-hearth Furnaces.—In 1905, Mr. S. Surzycki[2] gave an account of the operation of a 25-ton fixed open-hearth basic furnace at the Czenstochowa, Poland, in which continuous steel making, based upon the principle of the Talbot process, was carried out with success.

The operation was conducted by having two tapping holes at different levels in the furnace, instead of only one. The whole, or part of the contents of the furnace, could be therefore tapped as desired. In a 25-ton furnace, 40 to 45 tons of metal were charged, and from this 25 tons were tapped by opening the upper tap hole, leaving 15 tons of low carbon steel in

[1] "Iron and Coal Trades Review," vol. 80, p. 88.
[2] "Journal Iron and Steel Institute," 1905, I, pp. 112–121.

TABLE LXXVII

CHEMICAL CHANGES DURING THE HOESCH PROCESS

Sample taken at	Period.	Analyses of the metal					Analyses of the slag.								Charge and adjuncts.	Remarks.
		C %	Si %	Mn %	P %	S %	FeO %	MnO %	Al_2O_3 %	CaO %	MgO %	P_2O_5 %	S %	SiO_2 %		
12.1	1st Period.	3·28	0·32	0·96	1·86	0·132	—	—	—	—	—	—	—	—	Charge 51,310 lbs. pig, 4144 lbs. lime, 7582 lbs. Swedish ore, 1697 lbs. rolling mill scale.	Pig run in.
1.1		2·47	trace	0·17	0·59	0·102	—	—	—	—	—	—	—	—		
1.3		1·90	,,	0·22	0·47	0·098	10·25	5·03	1·36	41·56	4·32	22·85	0·069	12·20		
1.4		1·65	,,	0·22	0·37	0·098	7·06	4·96	1·38	45·48	4·00	22·36	0·124	11·80		
2.30		1·46	,,	0·34	0·26	0·082	4·67	3·93	1·60	48·86	4·00	22·13	0·138	11·40		
3.0		—	—	—	—	—	—	—	—	—	—	—	—	—	Charge 4804 lbs. spathic ore, 11,928 lbs. scrap, 2843 lbs. lime.	End of first period. Metal returned to furnace.
3.50	Finishing Period.	0·385	,,	0·29	0·090	0·10	19·64	13·49	3·17	33·64	6·92	6·25	0·110	14·20		
4.10		0·205	,,	0·23	0·050	0·089	15·78	12·08	3·00	35·78	6·70	6·70	0·165	15·40	Charged 210 lbs. rolling mill scale.	
4.30		0·090	,,	0·26	0·045	0·090	15·83	8·88	2·32	43·88	6·00	5·50	0·289	13·20		
4.45		0·075	,,	0·26	0·035	0·080	14·13	10·19	2·21	43·79	6·10	5·57	0·206	14·20	Charged 352 lbs. lime. At 4.55 453 lbs. lime.	
5.5		0·058	,,	0·27	0·035	0·078	16·23	8·32	2·20	45·30	5·90	5·55	0·275	14·00		
5.10		0·045	,,	0·25	0·030	0·077	17·20	7·67	2·00	46·19	6·12	5·15	0·316	13·10		
5.15		0·080	,,	0·47	0·040	0·067	17·03	10·25	1·90	46·28	5·92	5·00	0·344	12·40	440 lbs. ferro-manganese added.	Tapped.

the furnace. By additions of ore and lime, the bath of steel was raised to a highly oxidised state before fresh additions of molten pig iron were made, so that the reactions were promoted immediately the iron entered the furnace. The rapidity of the operation in the furnace was accelerated by treating the molten metal in the ladle with finely ground, heated ore, which was shovelled into the stream of iron as it was run into the ladles from the blast furnace, before it was charged into the open-hearth furnace. By doing this, less ore was required in the furnace.

The furnace used was 26 ft. 3 in. long between blocks, 8 ft. 7 in. wide, and 1 ft. 8 in. to 2 ft. deep. During its first campaign, 574 charges were made, and after repairing the ports and roof and repacking the regenerator chambers, the furnace made over 690 charges and was not worn out.

The pig iron used contained—

Carbon	up to 3·0 %
Graphite	„ „ 3·7 %
Silicon	0·8 to 1·9 %
Manganese	0·0 „ 1·5 %
Phosphorus	0·5 „ 0·8 %
Sulphur	0·02 „ 0·10%

The furnace produces 3 heats, each of 25 tons, per day of 24 hours, and the consumption of materials for one month is given below :—

	Tons.	Lbs. per ton of good ingots.
Cold pig iron	140·8	154·7
Molten „	1809·5	1991·0
Ferro-manganese	20·9	22·9
Scrap	19·8	21·8
Iron ore (Krivoi-Rog)	458·1	504·0
Lime	144·3	158·4
Aluminium	0·08	—
Burnt dolomite	107·7	118·4
Chrome ore	2·0	2·2

Products: 2003·7 tons good ingots; 41·8 tons scrap. Yield, 102·72 per cent. Number of days, 26. Production per day, 77·07 tons.

The Monell and Rees-James Process.—This process is a modification of the Monell process which was patented in 1900, and differs in principle from the Bertrand-Thiel or Hoesch process, in the employment of one ordinary open-hearth basic furnace, in which the phosphorus in the pig iron is rapidly reduced before much of the carbon is removed. The chief point of difference in working the process, is in bringing the oxides of lime and magnesia (which are charged into the furnace before the molten metal), to a very high heat, bordering on fusion. The result is a large formation of slag, while the relatively low temperature of the metal favours the rapid oxidation of phosphorus, silicon, and manganese, part of the carbon being reduced at the same time. About 80 per cent. of the slag is removed, and the bath, which is now in a favourable condition to be acted upon by the flame, is converted to steel in the ordinary way by the use of suitable oxides. The object of the process is rapid production.

A description of the Monell process, as used at the Homestead Steel Works, U.S.A., is given by C. W. Tideström.[1] It is stated that the hearth of the furnace consists of magnetite, and upon it are charged 3 tons of limestone, and afterwards 1·0 to 1·2 tons of preheated ore is charged, according to the amount

[1] "Bihang till Jernkontorets Annaler," 1903, pp. 351–368, 389–401.

of silicon in the pig iron used. In about 90 minutes, when the ore is nearly melted, 40 tons of molten pig iron are charged direct from the blast furnace. The action which ensues produces a thick foaming slag, during which most of the phosphorus, silicon, and manganese, and part of the carbon are reduced. In about 2 hours after the pig iron is charged, the large quantity of slag formed is tapped off through a hole about 4 inches above the surface of the metal, leaving a thin coating of slag, favourable to complete the decarburisation of the metal. The pig iron used contained, C, 3·90 per cent.; Si, 0·5 to 0·9 per cent.; Mn, 0·8 to 0·9 per cent.; P, 0·5 to 0·8 per cent.; S, 0·04 to 0·07 per cent.

The ore contained, Fe, 64·0 per cent.; Si, 3·0 per cent.; Mn, 0·1 per cent.; P, 0·1 per cent.

The slag analysis was, SiO_2, 20 per cent.; Fe, 20 to 25 per cent.; P_2O_5, 3 to 5 per cent.; Lime, 20 to 25 per cent.

From 16 to 18 heats were produced per week, yielding 650 to 700 tons of ingots equal to 100 to 102 per cent. of the charge. The time taken during each heat was from $7\frac{1}{2}$ to $8\frac{1}{2}$ hours.

The Knoth Process.—A molten metal process,[1] patented by Henry Knoth of Birmingham, Alabama, U.S.A., deserves mention, as it embodies part of the principle on which the Talbot continuous process is based, but is carried out in the ordinary fixed open-hearth furnace. Instead, however, of part of the steel being retained in the furnace, necessitating two tapping holes at different levels as in the Surzycki furnace, all the charge is tapped into a ladle, three-fourths of which is poured into moulds, the remainder being returned to the furnace after being mixed with fresh molten pig iron to make up the entire charge. The diluting of the pig iron with low carbon steel is said to shorten the process, but no details of the operation of a charge can be found recorded, and it seems to us that the Hoesch and Talbot processes are more economical.

[1] "Iron Age," vol. 70, p. 5.

CHAPTER XXVI

THE DEVELOPMENT OF THE OPEN-HEARTH FURNACE

Historical.—So much has been written about the difficulties experienced by the brothers Siemens in their endeavours to perfect their regenerative gas-fired furnace for steel manufacture, that it is only necessary here to make a very brief historical reference to the early stages in its development. Prior to the experiments of Sir W. Siemens and his brother Frederick, many inventors and others had devoted much time and talent to the improvement of the furnaces used for puddling iron, and for producing steel direct from the ore. The application to furnaces of regenerators for heating the air of combustion by the waste heat from the furnace, was a distinct and new feature in furnaces for steel heating and melting. It was several years after Frederick Siemens patented his furnace in 1856, which is illustrated in Fig. 123, before it was adapted to steel manufacture with any commercial success.

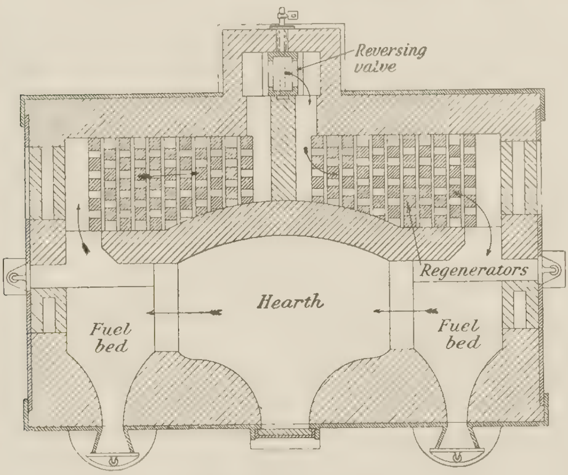


FIG. 123.—Siemens' First Furnace with Regenerators.

For reheating steel, Siemens had soon ample proof of the success of his furnace, and this encouraged experiments with it for steel melting. In 1862, Siemens designed a furnace for Chas. Attwood, of Towlaw, Durham, and in the following year a large furnace was built at the Montlucon Works in France, and operated by Dr. Otto Siemens, both furnaces being for steel manufacture. Neither furnace gave the commercial results looked for, and Siemens obtained works in Birmingham, afterwards called his Sample Steel Works, with the object of perfecting his design. At these works he conducted many experiments, and while improving the design of his furnace, he was also establishing, upon an enduring foundation, the process of steel manufacture which is known by his name.

At the works of the Bolton Steel Co. and the Barrow Hematite Co., Siemens' gas-fired regenerative furnaces had been employed for puddling iron and for heating steel respectively, prior to 1866–7, but during these years the furnaces were used for a short time for steel manufacture. The results obtained did not satisfy Siemens, and he made further experiments at his own Sample

Works in Birmingham, and ultimately, in 1868, the Landore Siemens Co. was formed. In the same year, his furnace was installed at the Crewe Works of the L. & N. W. Railway Co. by Ramsbottom, who was then engineer. It was used for the manufacture of steel by the pig and scrap process, which had been developed by the brothers Martin, of Sireuil, in France, who had been experimenting with the Siemens furnace (for which they had a licence), while Siemens was conducting his experiments in Britain.

Development in Design.—The development in the design of the open-hearth furnace and the perfecting of the processes conducted therein, went on simultaneously. The high temperatures necessary to produce the desired results in steel-making were very severe upon the materials which formed the linings of the furnaces. The temperatures affected some parts of the furnace more than others, which led to modifications in the form of the roof, hearth, ports, and regenerators. Improvements were made also in the flues and valves, with the object of obtaining a higher efficiency from the various kinds of fuels used. During more recent years, since the introduction of the basic lining, tilting furnaces have been employed to facilitate the control and removal of the slags which are formed during the process of steel manufacture. These tilting furnaces have been developed on a very considerable scale with great success, for the production of large outputs of steel. From the following description of the gradual improvements in the design of the open-hearth furnace, it will be observed that the modern furnace has reached its present stage of development as the result of the labours of many experimentalists, with ample evidence of which the Patent Office records abound.

First Open-hearth Furnace with Regenerators.—In Fig. 123, to which reference already has been made, a sectional plan is shown of the first furnace with regenerators, for which Fred. Siemens obtained a patent in 1856. The regenerators shown behind the furnace were intended for heating the air only, which united with the gases from the solid fuel as they passed into the furnace. The brickwork in the regenerative chambers absorbed the heat from the waste gases on their way to the chimney, and when the valve was reversed, which admitted air to the regenerator, through which the hot gases had just ceased to pass, the brickwork gave up its heat to the cold air on its way to the furnace.

Siemens claimed in his patent that his furnace was applicable to the use of gaseous or solid fuels, and in this design are found the elements of the regenerative principle as applied to the open-hearth and other steel heating and melting furnaces.

In a paper [1] contributed to the Institution of Mechanical Engineers in 1857 by Mr. C. W. Siemens, he said that the invention of the regenerative furnace was due to his brother, Mr. Frederick Siemens, and that the saving in fuel effected thereby over the plants in common use at that period amounted to from 70 to 80 per cent. Fig. 124 shows the furnace as illustrated by Mr. Siemens, and it will be observed that the regenerators are under the furnace, and not behind, as shown in Fig. 123.

For some years this type of furnace, in a modified form, was used at the steel works of Messrs. Marriot & Atkinson, of Sheffield,[2] for heating steel. Instead of using two fireplaces and one heating chamber, as shown in Fig. 124, a furnace with one fireplace and two heating chambers was used, having a regenerator at the end of each heating chamber. The reason for abandoning the furnace with two fireplaces was that both fireplaces had to be traversed in succession by the heated air, so that the fuel of the second fireplace was consumed to no purpose.

[1] "Proceedings Inst. of Mechanical Engineers," 1857, pp. 103–111.

[2] *Ibid.*, 1862, p. 23.

Gas and Air Regenerators.—It was not until the brothers Siemens introduced their Gas Producer and Regenerators combined, in 1862, that the principle of regeneration was applied to the heating of both gas and air. The

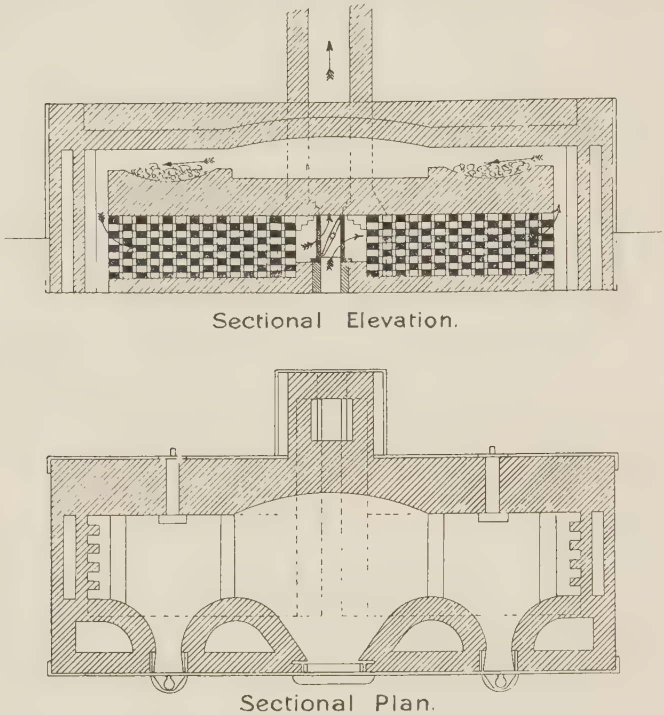


FIG. 124.—Siemens' Furnace with Regenerators below Hearth.

type of producer used is shown in Fig. 186, Chapter XXXI on Gas Producers. The regenerators consisted of one chamber, built below the furnace, having four separate compartments, two of which were in communication with each end of the furnace, and arranged with valves which provided practically the

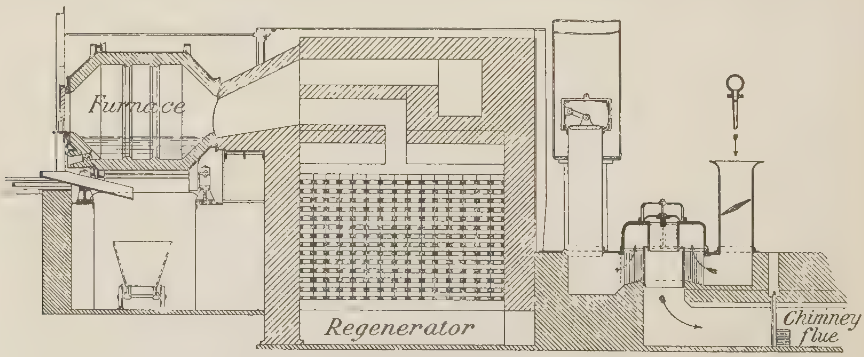


FIG. 125.—Siemens' Rotating Furnace (1872).

same reversing action, with slight mechanical differences in design, as found in furnaces of to-day.

Rotating Furnace.—In 1872, C. W. Siemens patented a rotating furnace, with which he used four regenerators. His object at this time was the direct production of steel from the ore. In this furnace he used a lining made of calcined bauxite, originally suggested to him by M. Le Chatelier. As very satisfactory results were obtained with this furnace at his Sample Works in Birmingham, works were erected at Towcaster, Northampton, and started in 1875. They did not prove, however, to be profitable, and were therefore discontinued. It is nevertheless interesting to note that Siemens did operate a rotating furnace successfully, in view of the advantages obtained from tilting furnaces to-day. Fig. 125 shows a sectional elevation of Siemens' furnace.

Pernot's Open-hearth Rotating Furnace.—In 1874, the Pernot Rotating Furnace was installed at St. Chamond, France. It consists of a circular hearth mounted on a truck at an angle of 5 to 6 degrees from the horizontal. The truck is of special design, having a roller path on which the furnace rotates by means of suitable gearing. The combined truck and hearth can be drawn

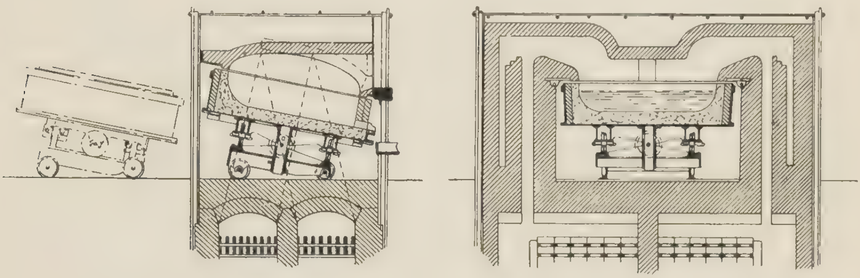


FIG. 126.—Pernot's Rotating Furnace.

from the furnace chamber on rails. Fig. 126 shows the furnace truck in position, standing upon the top of the regenerator chambers.

The object of the rotating inclined hearth is to expose more completely the melted and unmelted portions of the charge to the action of the flame. The charge of pig iron and scrap is heated to redness before being charged. The cost of the furnace appears to be a barrier to its general use, although it is stated that very good steel was obtained from it. Jeans says[1] that the cost of a furnace capable of working a charge of 5500 lbs. is about £1200, including motive power.

Regenerators with Dust Pockets.—In 1875, C. W. Siemens introduced a simple and effective means of preventing mill scale and other iron dust in the form of oxides, and also liquid slags, from getting into the regenerator chambers and checker bricks. The intense action of the hot gases, laden with dust particles, also fused the surface of the brickwork at the bulkheads and produced slags which trickled down upon the checker work in the chambers. In Fig. 127 it will be observed that the flue from the furnace ports at each end of the furnace drops vertically between the air and gas regenerators, extending beyond the port holes, which enter the slag pockets laterally. Doors are provided at the bottom of each slag pocket through which slag may be removed periodically.

Rotating Furnace with Blast Pressure.—The rotating furnace illustrated in Fig. 128 was patented by J. K. Johnson in 1876, with the object of promoting more rapid manufacture of steel by sending streams of air under pressure through the metal, from tuyeres arranged below the hearth of the furnace. In

[1] Jeans, "Steel," p. 464.

addition to the blast under pressure, a gas supply, with suitable admixture of air, was also delivered to the rotating furnace through the end ports. The

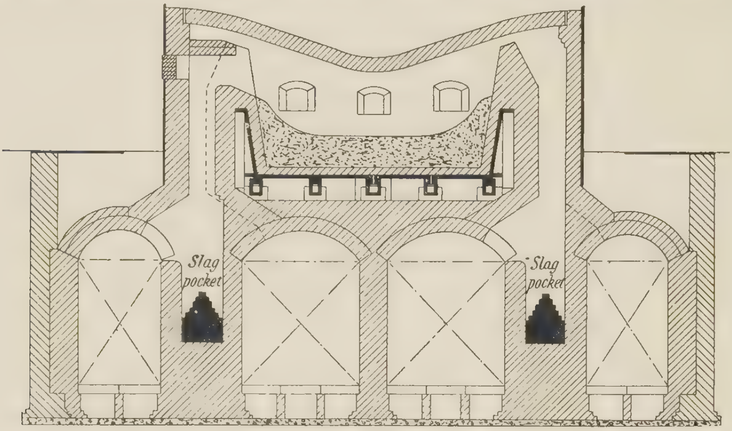


FIG. 127.—Siemens' Furnace with Dust and Slag Pockets.

furnace was mounted on a special truck, upon which it could be rotated to uncover the tuyeres when the blast was not required, and for discharging the metal after the completion of the operations. The whole furnace could be moved bodily on the truck, from between the fixed gas and air ports, as desired. The blast pipe connections to the blast box were made by means of a flexible pipe. The use of blast in the manner described, recalls the experiments of George Parry at the Ebbw Vale Iron Works in 1855.

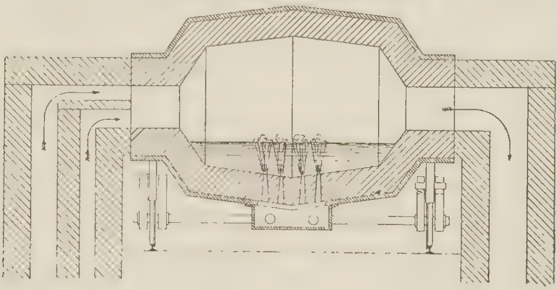


FIG. 128.—Rotating Furnace with Air Blast.

Protecting Furnace Roofs.—Furnace roofs are generally made of silica bricks for both acid and basic furnaces. Modifications in the design of roofs have been made from time to time, with the object of obtaining a higher efficiency from the furnace, and also in reducing the wear of the materials forming the roof. The change effected when the arched roof replaced the depressed roof was advantageous. In Fig. 129 are shown sections of a water-cooled furnace roof, for which a patent was obtained by W. L. Wise in 1875. It consists of a series of

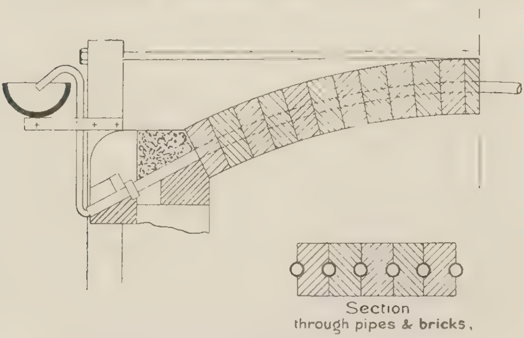
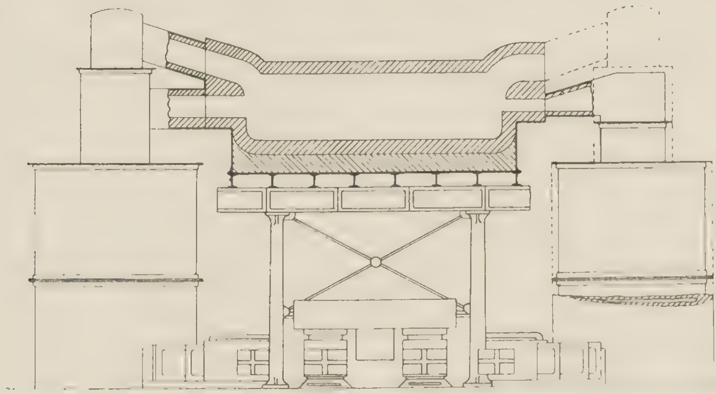


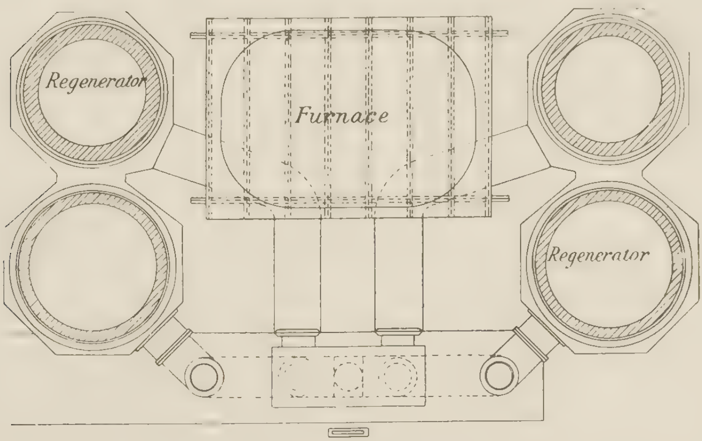
FIG. 129.—Water-cooled Furnace Roof.

special bricks arranged to form the furnace roof, through which pipes pass right across the crown of the furnace, as shown in Fig. 129. The brickwork is kept cool by the free circulation of water.

Regenerators at the Ends of the Furnace.—In 1877 C. W. Siemens obtained a patent for a furnace in which the regenerators were placed at the ends of the furnace instead of underneath. This was an improvement upon the latter arrangement, which may be found in some works to this day, although



Part Sectional Elevation



Part Sectional Plan.

FIG. 130.—The Batho Furnace.

defective due to the risk of a running bottom playing havoc with the chambers below. In modern furnaces the regenerators are placed at the ends of the furnace or underneath the working platform. When the regenerators are placed below the hearth, it is usual to have a vault immediately below the centre of the hearth between the regenerators.

In Fig. 130 is shown a furnace with four regenerators built outside, and entirely clear of the furnace hearth. It is known as the Batho Furnace. The regenerators are built in the form of cylindrical tanks, from which the flues are

connected with the furnace ports and reversing valve-box, as shown in the illustration. One of the advantages claimed is the ease with which the regenerators can be examined and repaired.

Basic Lining for Furnaces.—It was in 1878 that S. G. Thomas patented the mixture which led to the success of the basic linings for both open-hearth furnaces and Bessemer converters. The mixture proposed consisted of finely-ground magnesium limestone, with a solution of silicate of soda about 8 or 10 per cent. of its weight. When used in an open-hearth furnace, it was rammed round the bottom to form the hearth. Several modifications were made in the mixture first patented, which formed the subject of subsequent patents, before success was assured. Fuller reference is made to basic linings and their compositions, in Chapter II, Section III, on " Refractory Materials."

Furnace Port Construction.—For some time after Siemens introduced his gas-fired furnace with regenerators, the method of constructing the ports remained the same, that is, the gas and air ports were built through the ends of the furnace at about the same level. It was found, however, that the roof near to the ports wasted rapidly by the action of the incoming gases, and the ports also suffered by the cutting action of the flame as the gases left the furnace. This led to the ports being made longer and narrower, and the air ports being placed a little higher than the gas ports, to promote better combustion and a freer mixture of both gas and air.

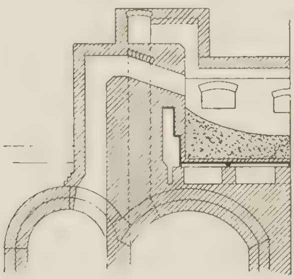


Fig. 131.—Hackney Furnace Ports.

Several modifications of the original form of ports have been suggested and tried; some have either proved effective or led to a more durable construction. The following patents indicate some of the improvements suggested.

Air Ports through Crown of Furnace.—Hackney in 1878, and Hackney and Wailes in 1882, patented furnace ports in which the air entered through the crown of the furnace, descending vertically or at an angle towards the hearth, and mixing with the gases issuing from the gas port through the end of the furnace. In the later patent, the same arrangement of ports was maintained, but

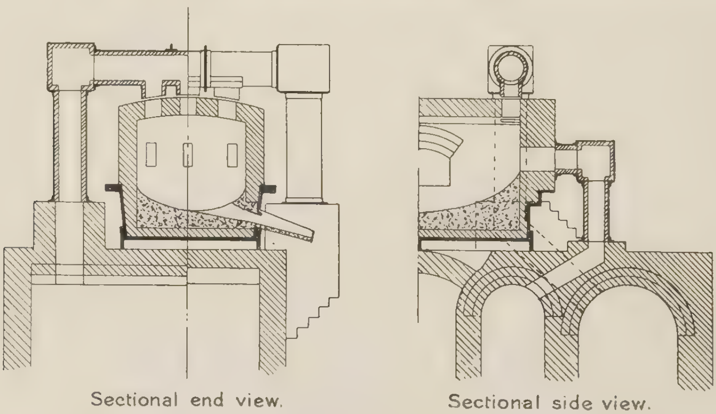


Fig. 132.—Hackney and Wailes Furnace Ports.

an auxiliary combustion or working chamber was built independently of the furnace, but connected with it by means of comparatively light and portable

pipes, lined with refractory materials. Figs. 131 and 132 show the Hackney and Hackney and Wailes' ports respectively.

Gas Port with Surrounding Air Port.—In Fig. 133 is shown a sectional elevation of a furnace port patented by Dietrich in 1893. He had two objects—(1) To make the end of the furnace through which the gas and air ports enter, of a jointless mixture of refractory material; and (2) To use gas regenerators only, the air of combustion being admitted through a valve at the end wall of the furnace, combining with the gas in the combustion chamber. We are not aware that this type of port has been tried.

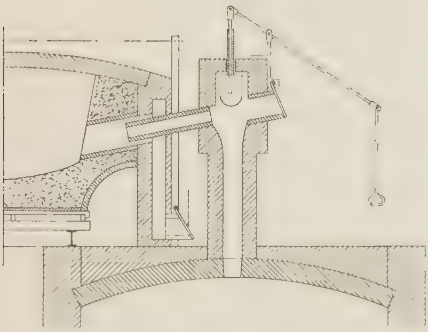


FIG. 133.—Dietrich Furnace Port.

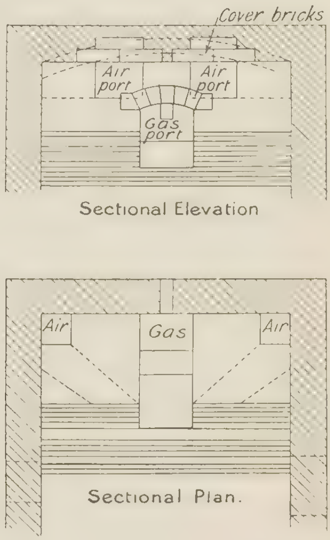


FIG. 134.—Robinson and Pope's Furnace Ports.

Facilities for examining Air Ports.—In 1894, Robinson and Pope patented a means whereby the two air ports could be easily examined by removing a tile from the roof of the furnace over each of the ports. By this means, labour and expense in repairs were saved. Fig. 134 shows one end of a furnace with the gas and air ports, the latter being covered with tiles.

Furnace with Movable Roof.—The convenience of lifting off the furnace crown, for charging heavy masses of material, which could not be charged through the ordinary doorways of the furnace, is found advantageous under certain circumstances. F. W. Dick and J. Riley obtained a patent in 1883 for a furnace with a movable roof. With such a roof, charging can be performed much more rapidly than by hand, as truck-loads of small scrap and pig can be emptied upon the hearth by the aid of an overhead crane, also large masses of scrap steel can be lowered upon the hearth conveniently. Modern charging machines have now supplied the means of rapid charging, although to this day furnaces are used with loose tops. While visiting the works of Messrs. Jones and Laughlin in Pittsburg, U.S.A., in the summer of 1912, we saw a 25-ton acid-lined furnace with movable roof, in which very large lumps of steel, such as old mill pinions, and other heavy castings weighing several tons, could be placed. Truck-loads of lighter scrap and pig could be tipped also on to the hearth. This furnace was used almost entirely for producing steel for foundry castings.

Fig. 135 shows Dick and Riley's arrangement.

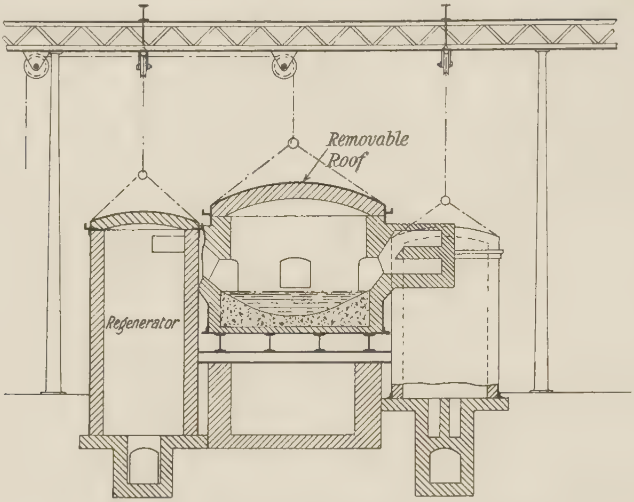


FIG. 135.—Dick and Riley's Removable Furnace Roof.

Furnace with Gas Producer, Regenerator, and Hearth combined.—In 1884, F. Radcliffe, of Woolwich, patented an open-hearth furnace with the gas producer and regenerator as part of the furnace structure. The regenerator chamber was of special construction, and was placed above the furnace. In Fig. 136 is given a sectional view of the arrangement. The gas goes direct

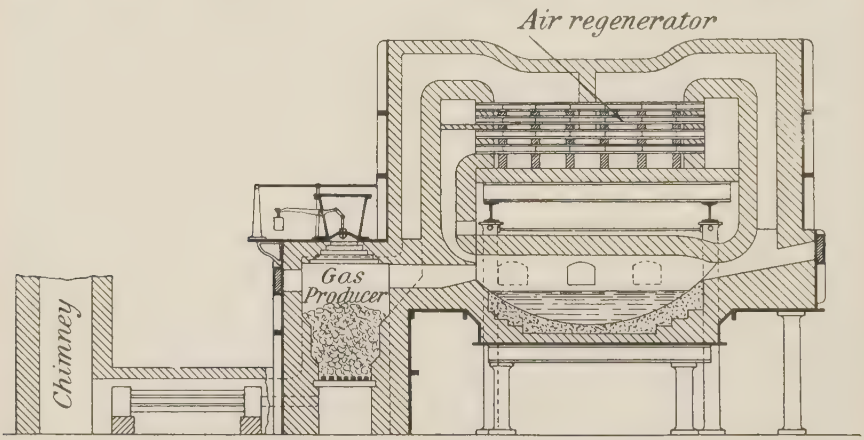


FIG. 136.—The Radcliffe Furnace.

from the producer to the hearth of the furnace, mixing with the air which passes through a series of pipes made of refractory materials and placed in rows in the regenerator chamber. These pipes are heated by the waste gases, which rise from the furnace and pass around them on their way to the chimney. The air used in the gas producer is heated by being passed through pipes arranged in the chimney flue, which receive heat from the waste gases. In a modified form,

this furnace was used very successfully at Woolwich Arsenal and elsewhere. There were, of course, no reversals in the direction of the furnace gases.

Subsequently, in 1885 and 1887, patents were obtained by J. T. King and H. Burrows respectively, for furnaces with regenerators built after the same principle as the Radcliffe furnace, but arranged differently in relation to the hearth of the furnace.

Regenerators at One End of Furnace only.—In 1885, F. Siemens patented a furnace having one set of regenerators only, placed at one end of the furnace. The flame swept round the furnace and passed down side ports to the regenerators below, and from thence to the chimney. The two regenerators were arranged for heating air only, and were used alternately by periodic reversals as follows:—The gas from the producer mixed with the air passing from regenerator on the right-hand side, and when the flame had made its journey round the hearth of the furnace, the spent gases swept out at the left-hand side port and through the other regenerator to the chimney. When the air valve was reversed, the same action took place in the opposite ports and regenerators. This furnace, which is known as the "New-Form" Siemens Furnace, is particularly well adapted for small charges from say two to five tons. The intense heat generated is sometimes very severe upon the brickwork where the flame strikes the walls before sweeping back to the outlet port. If no obstacles, such as door jambs, were in the way to interfere with an easy passage of the flame, less wastage of brickwork would take place. Fig. 137 illustrates the furnace.

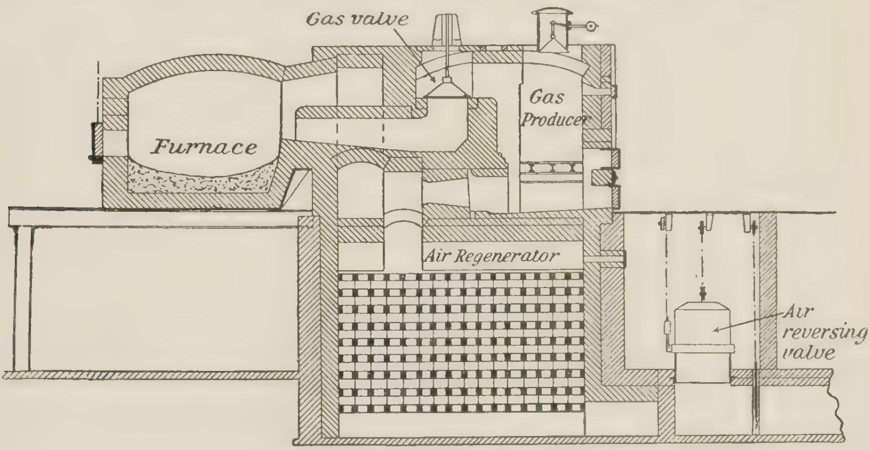


Fig. 137.—Siemens' "New-Form" Furnace.

The "Ideal" Open-hearth Furnace.—B. H. Thwaite, in 1891, obtained a patent for a high-temperature regenerative furnace, in which he claimed that both gaseous and liquid fuel could be used. In Fig. 138 is shown a sectional elevation of the furnace. The object was the more complete utilisation of heat in the open-hearth furnace than by any other design of regenerative furnace.

Thwaite's furnace was designed upon theoretical lines, and in his opinion represented the ideal furnace. The regenerators, or what he termed recuperators, are shown above the furnace hearth, and are for heating the air only. They are separated by a central flue, at the bottom of which is the air inlet, through which air under pressure from a fan is admitted and circulates in turn through each recuperator. The incoming gas passes through a brick baffler,

and mixes with the heated air from the recuperator before reaching the furnace

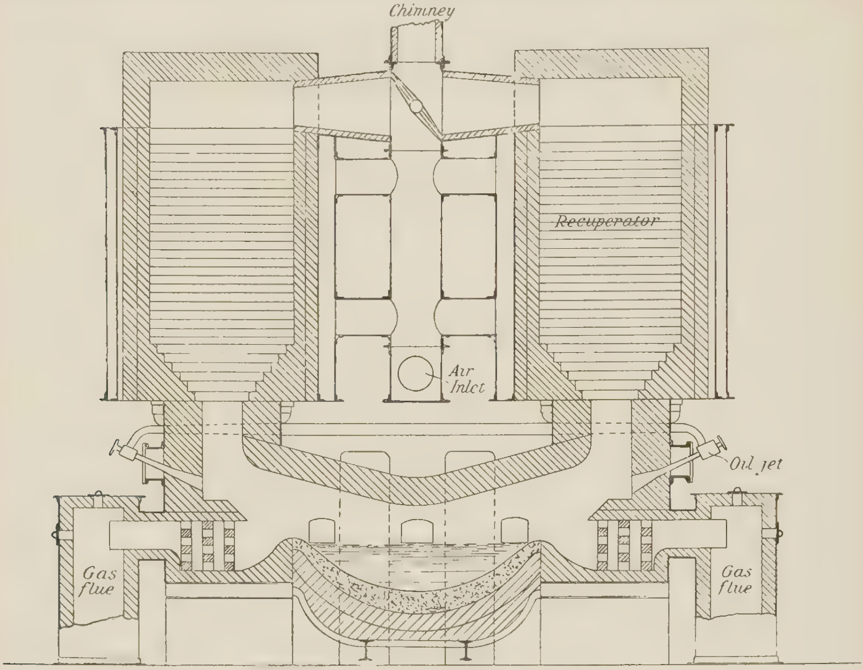


FIG. 138.—Thwaite's "Ideal" Open-hearth Furnace.

hearth. The waste gases pass up the recuperator at the opposite end of the

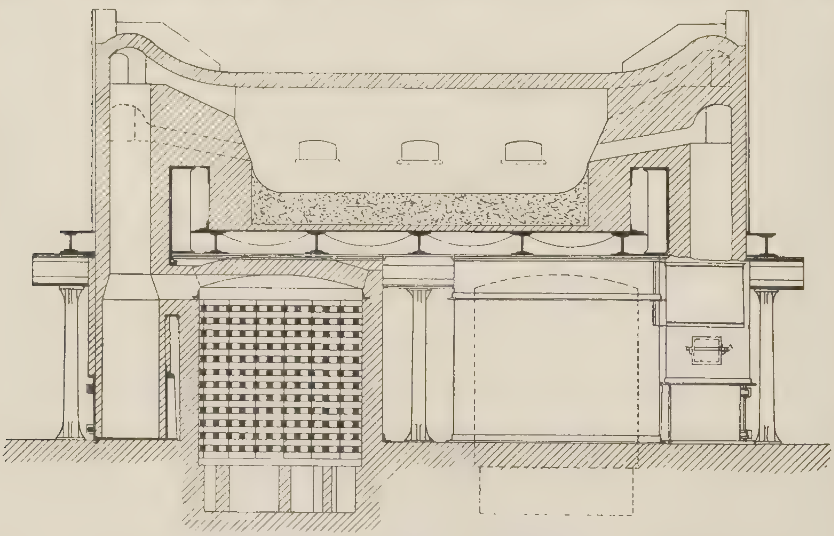


FIG. 139.—Duff Open-hearth Furnace with Improved Regenerators.

furnace, at the same time heating the baffler bricks as the gases sweep out of

the furnace. A chimney surmounts the central flue, and immediately below the chimney is placed the air reversing valve. This valve, and also the gas valve, are connected and automatically controlled and operated.

When oil fuel is used in the furnace, it is admitted above the baffler bricks at each end and mixes with the air as it descends from the recuperators.

Improved Arrangement of Regenerators.—In Fig. 139 is shown a part sectional elevation of a furnace with regenerator and flues, for which Duff secured a patent in 1892. He arranged the regenerator chambers below the furnace in such a position as to admit of their being built quite independent of the furnace, with short flues branching into the vertical uptakes connecting the ports and regenerators. The uptakes extended downwards, below the branch flues from the regenerators, forming liberal slag pockets which could be cleaned periodically. As far as the slag pockets are concerned, this design differs from C. W. Siemens' design of 1875, in that the slag pockets are outside the regenerators instead of between them.

Furnaces with Double Hearths.—Several patents have been obtained for furnaces with two hearths. In 1887, G. Hatton patented a rotating furnace, the hearth and roof of which could be used alternately for the charge, the door and tapping hole being midway between the roof and hearth, and on one side of the furnace only. In 1890, G. Rodgers obtained a patent for a double hearth in a fixed furnace, as shown in Fig. 140, which had for its object the tapping of each bath of metal at different times.

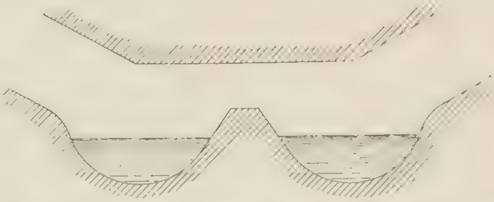


Fig. 140.—Section through Bottom of Double Hearth (Rodgers').

Saniter in 1900 and Talbot in 1901, also patented furnaces with double hearths for continuous operation. It is somewhat doubtful whether the economy and convenience of such an arrangement are very appreciable, except under very special circumstances.

Furnaces with Tapping Holes at Different Levels.—In Saniter's patent of 1900, he embodied the idea of two tapping holes from the furnace hearth, and Surzycki in 1902, patented a furnace with a deep hearth having tapping holes at different levels, with the object of continuous melting. The upper tap hole could be used time after time without disturbing the metal in the bath below. The bottom tap hole was only opened as required for emptying the furnace or repairing the bottom. Surzycki's furnace has been used very successfully[1] for continuous steel manufacture in this way. Fig. 141 shows the arrangement of tapping holes.

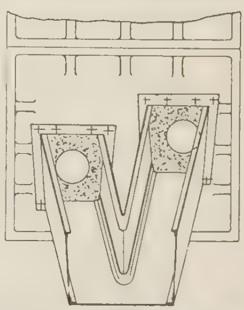


Fig. 141.—Furnace with Tapping Holes at two Levels (Surzycki's).

Tilting Open-hearth Furnaces.—The value of the tilting furnace in open-hearth steel manufacture is found in dispensing with the ordinary tapping hole, and is practically demonstrated when used for the basic process by the ease with which slags can be removed as required. It is also of special value in the continuous process of steel manufacture, where only part of the charge is poured from the furnace at one time. Several kinds of furnaces have been patented and employed for

[1] "Journal Iron and Steel Institute," 1905, I, p. 112.

steel making, most of which differ chiefly in the mechanical features of design.

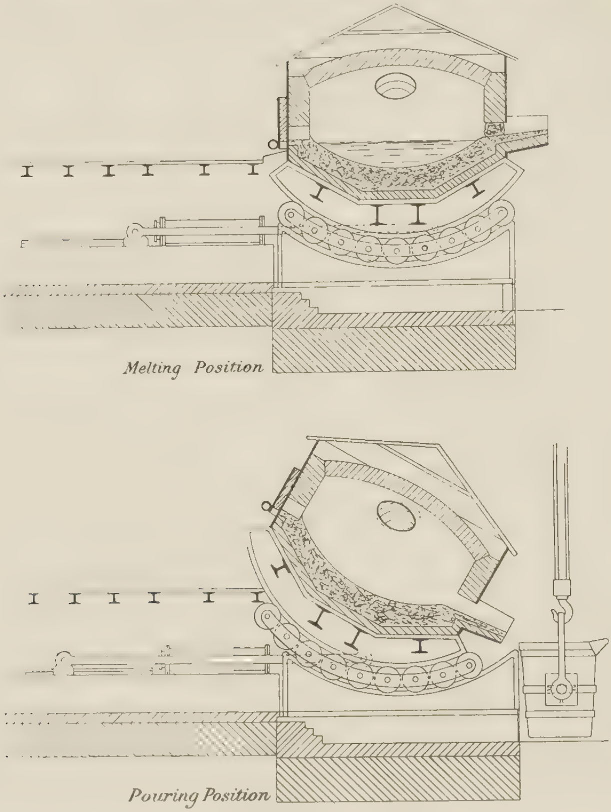


FIG. 142.—Campbell Tilting Furnace.

In 1889, the Campbell furnace, now so well known in America, was introduced at the works of the Pennsylvania Steel Co. by H. H. Campbell, the designer. In Fig. 142 is shown sectional elevations of the furnace. It is operated by means of a hydraulic cylinder and ram fixed horizontally to the furnace foundation, the ram being attached to the bottom of the furnace. The furnace rotates about its own axis in circular roller paths. The port holes are oval in the movable part of the furnace, and coincide with the fixed gas and air ports when the furnace is in a horizontal position. Much improvement has been made in the Campbell furnace, both in construction and means of tilting, since first designed.

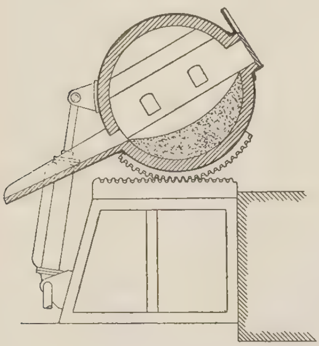


FIG. 143.—Wellman Tilting Furnace (1895).

In Fig. 143 is shown a sectional elevation of the furnace patented by Wellman in 1895. The furnace proper is cylindrical in form, to the bottom of which is fitted a toothed segment which engages in a rack mounted on foundation standards. The tilting is done by means of a hydraulic

cylinder and ram. The gas and air ports shown coincide with the fixed ports from the regenerators when the furnace is in a horizontal position.

In 1898, a modification of the foregoing furnace was patented by G. J. Johnson for the Wellman Seaver Eng. Co. Instead of using the rack and toothed segment, the furnace is supported upon rockers which permit of its being tilted to discharge its contents. The hydraulic cylinder with ram and attachments, provide the means for tilting the furnace. Fig. 144 shows the improved design.

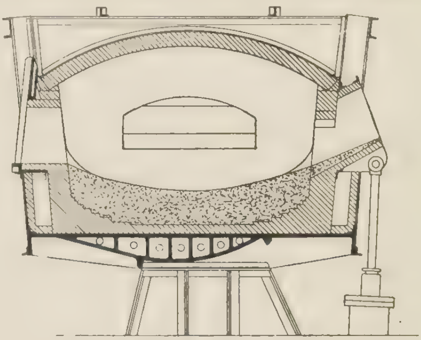


FIG. 144.—Wellman Tilting Furnace (1898).

Benjamin Talbot in 1900, patented a movable flue connection to work in conjunction with the Wellman tilting furnace. Fig. 145 shows a sectional elevation of the flue at the junction of the uptake and the side wall of the furnace. The faces of the flue at the junctions are water-cooled, as well as the top of the uptake flue and face of the wall of the furnace round the ports. The movable flue is arranged in a frame mounted on rollers, and can be moved a few inches from the face of the furnace when it is being tilted.

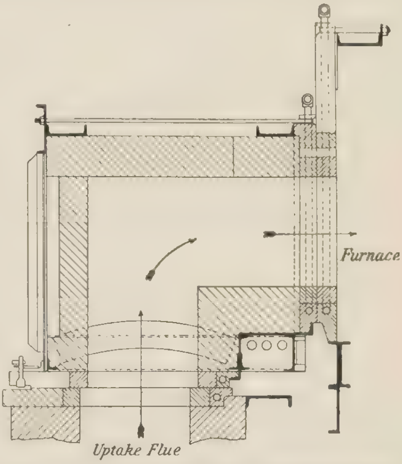


FIG. 145.—Talbot's Water-cooled Movable Furnace Flue Connection.

In the latest design of Wellman furnace, a water-seal is provided at the junction of the air and gas uptakes from the regenerators with the movable flue. It is so arranged that a small movement of the port can be made without breaking the water-seal.

Furnace with Air Regenerators and Gas Producers combined.—In 1907, F. Siemens obtained a patent for a gas-fired furnace in which gas was admitted at each end of the furnace alternately from gas producers forming part of the main structure. In Fig. 146, which shows a sectional elevation of the furnace, it will be observed that the two gas producers are connected by an overhead conduit, and that the supply of gas to each end of the furnace alternately is controlled by two valves, one of which is open while the other is shut. The air is passed through the regenerators to the furnace in the ordinary way. Two regenerators only are used, both being placed under the furnace.

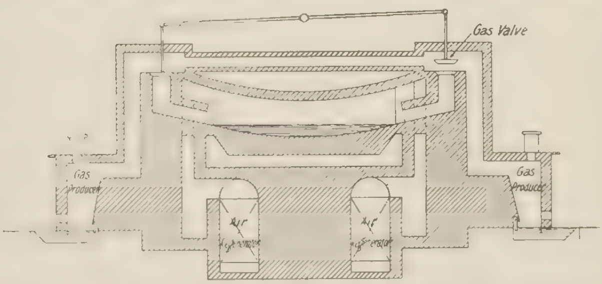


FIG. 146.—Siemens' Furnace with Gas Producer at each end.

Furnaces with Liquid Fuel.—During recent years, the application of liquid fuel to the open-hearth furnace has developed in countries where oil can be obtained more cheaply than coal for producing gas. Numerous designs of burners for the use of liquid fuel are employed with success in large and small open-hearth furnaces. It is unnecessary to alter the construction of the ordinary open-hearth furnace to employ a liquid fuel burner, but it is a common practice to make use of the gas and air regenerators for heating the air for combustion only. When oil fuel is used, it is only necessary to make a hole through the bulkhead at each end of the furnace, through which the oil burners are inserted. The burners are of course used alternately, the one not in action being withdrawn sufficiently to prevent it from being damaged by the flame. This is easily performed, as the connections to the burner are flexible.

The oil is pumped under pressure to the burner, and steam or air under a pressure of usually about 40 lbs. per square inch is passed through the burner for producing the necessary volatilisation of the oil. The hot air from the regenerators mixes with the fuel in the port just before entering the hearth of the furnace.

In Fig. 147 is shown one of the many improved types of burners. It is the

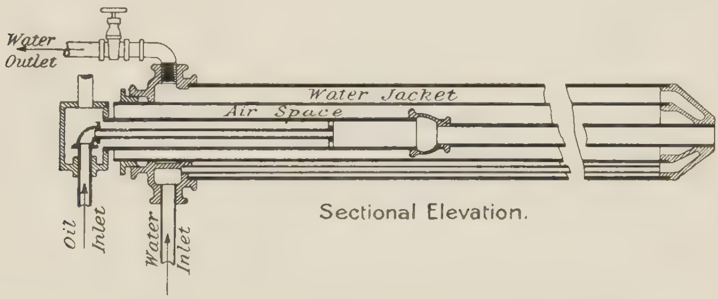


FIG. 147.—Liquid Fuel Burner for Open-hearth Furnaces.

patent of Mr. C. H. Speer, who with Mr. W. M. Carr has made several improvements in oil-fired furnaces in the U.S.A. Speer's improved burner is made with the object of avoiding the removal of the idle burner from the furnace while the other one is active. To effect this, a water-jacket (through which a liberal circulation of water is kept up) surrounds the burner and keeps it relatively cool. The water is carried to the end of the water-jacket by a small pipe indicated on the sketch. Between the water-jacket and the burner proper is an air space which prevents chilling of the fuel vapour and air or steam passing through the inner pipe, and at the same time protecting it from the intense action of the flame. Fig. 148 shows the burners in position, the ends

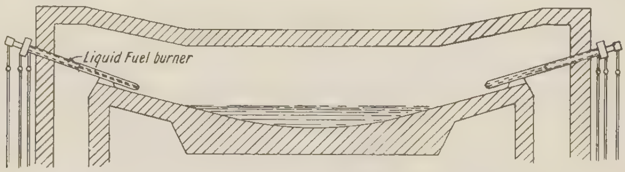


FIG. 148.—Liquid Fuel Burners in Position.

of each burner being supported on a small block of refractory material resting on the port of the furnace.

With reference to the position of the oil fuel inlet to the furnace—it has been suggested to introduce the burners at the top of the regenerator chambers.

Conclusions.—From the foregoing descriptions it may be concluded that the modern open-hearth furnace differs only in small details from the original furnace designed by Siemens Brothers. The principle of regeneration is the same to-day as when applied in 1856 by Frederick Siemens. The introduction of the gas producer was a step forward, as the use of four instead of two regenerators became possible, hence both gas and air were heated before mixing in the furnace. Improvements in the relative sizes and position of air and gas ports have increased the durability of the furnace lining and ports.

Some of the many patents have never assumed any practical shape, but have nevertheless indicated lines upon which improvements could be made.

The most noticeable feature of the modern furnace when compared with the first furnaces employed for steel making, is the magnitude of the capacity. Furnaces of the fixed type are made as large as 180 tons capacity, while the tilting furnace of the Talbot continuous type are made to take 250 tons.

In the following chapter on "The Design of Fixed Open-hearth Furnaces," details of furnace construction are given more fully.

CHAPTER XXVII

THE DESIGN OF FIXED OPEN-HEARTH FURNACES

In the design of furnaces of the Siemens or Open-hearth type, some difference of opinion exists on minor points, but there are certain considerations which must be observed if good results are to be obtained from the furnaces. It is not so important that the form of furnaces, or the methods of building them, be alike, as that the relative proportions of the working parts be correct. These proportions differ only very slightly whether the furnace be fixed open-hearth, basic or acid, or of the tilting type. In the case of open-hearth fixed furnaces used for the continuous processes, variations occur in the sizes of the hearths in relation to their capacity, but in other respects the design differs only in a small degree.

The Open-hearth Fixed Furnace

The open-hearth furnace proper consists of two main parts, (1) the melting hearth, and (2) the regenerators, but in addition to these are the flues and ports which connect them, and which play an important part in the efficient working of the furnace. There are also the valves which regulate the supply of air and gas, and the chimney or stack for carrying away the spent gases. The supply of fuel, and the relation of the gas producer to the size of the furnace (or the size of the pipes if the supply of fuel be natural gas or oil instead of coal), have an important bearing on the design of the furnace.

The following will therefore be considered :—

(1) General details of furnace.
(2) Hearth.
(3) Regenerators, including slag pockets.
(4) Valves and flues.
(5) Chimney.
(6) Gas producers.

General Details of Furnace.—Plate VI illustrates a modern fixed open-hearth furnace, which is a marked improvement upon the older form of furnace shown in Fig. 149. The body of the furnace is supported upon concrete foundations, quite independently of the regenerator chamber walls. The bottoms and sides are built up usually of cast iron or cast steel plates bolted together. These are further tied by means of rolled steel joists placed vertically against each side of the furnace and outside the plates, having their bottom ends secured to the foundation girders and the free ends over the top of the side plates tied with cross stays. The ends of the furnace are usually unplated, but vertical rolled steel joists, such as are used for the sides of the furnace, are used at the ends, with strips of rolled steel placed between them and the brickwork. Long ties, stretching the full length of the furnace above the roof, hold together the end uprights (or buckstays, as they are called). The brickwork uptake flues from the regenerators are, as a rule, held together in the same way by means of ties, plates, and joists.

The doors are operated by hand, hydraulic power, or electric power. Either

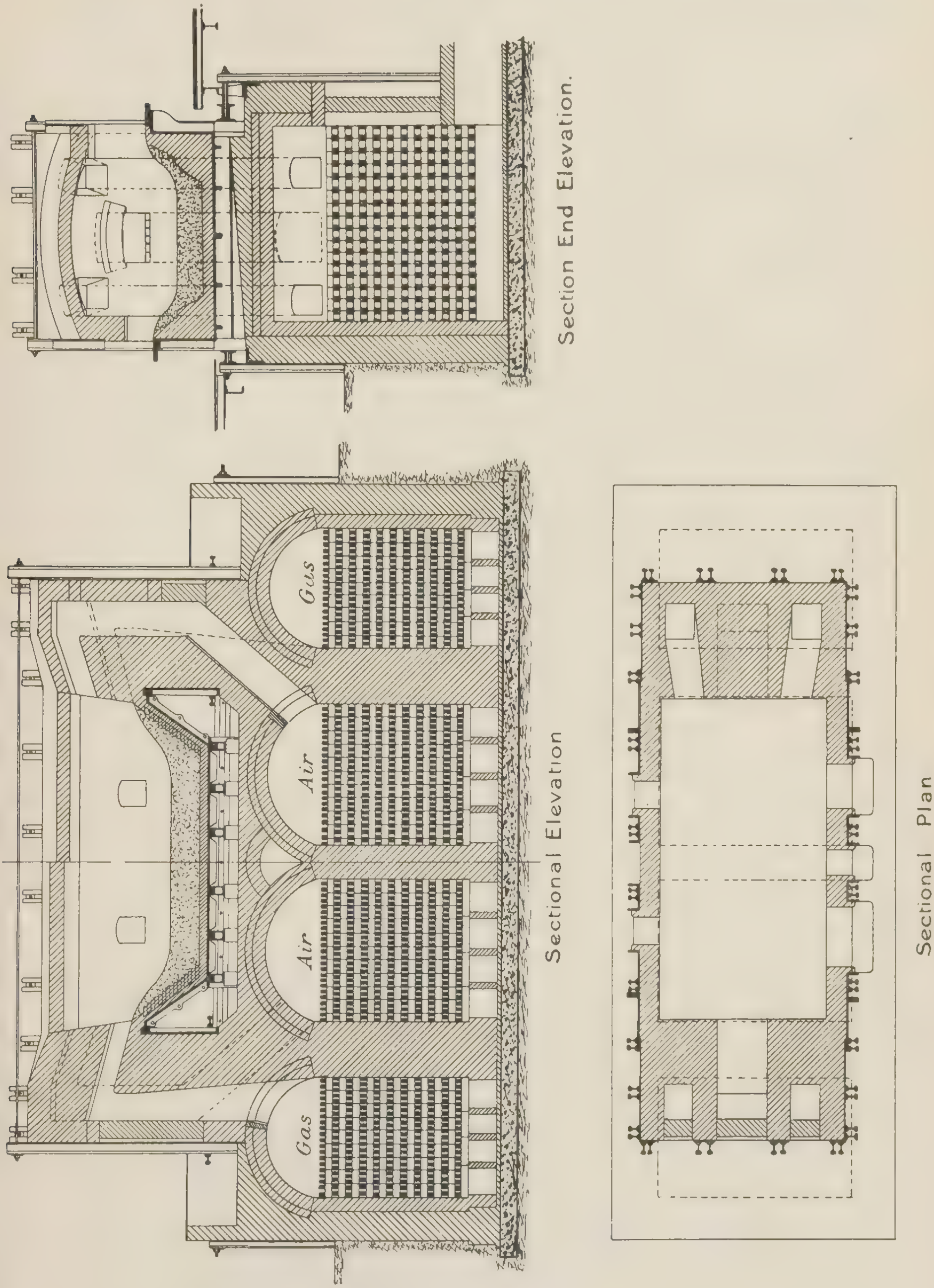


FIG. 149.—Acid Open-hearth Furnace with Regenerators below Hearth.

of the two latter methods are necessary for large furnaces. In Chapter XXVIII, the question of water-cooled doors and frames is discussed, and from the point

of view only of comfort to the melter in examining the furnace without scorching his face, their adoption is advisable. A man will not take the same care of the furnace if each time he goes to examine it he is subjected to unbearable heat.

The charging platform at the furnace is supported by girders and columns, and is fitted, in the case of large furnaces, with rails, upon which the electric charger operates. A track is also placed alongside the front of the furnace, or behind the charging machine on the platforms, for the cars of raw materials. General arrangements of furnaces, mixers, cranes, etc., are given in Chapter XXXII.

Hearth.—Fig. 150 shows a modern form of fixed hearth, the bottom of which is made of cast steel plates, securely bolted together and supported upon steel girders. Refractory materials for the lining are built upon the steel plates, and ultimately the hearth is shaped to the depth and form required.

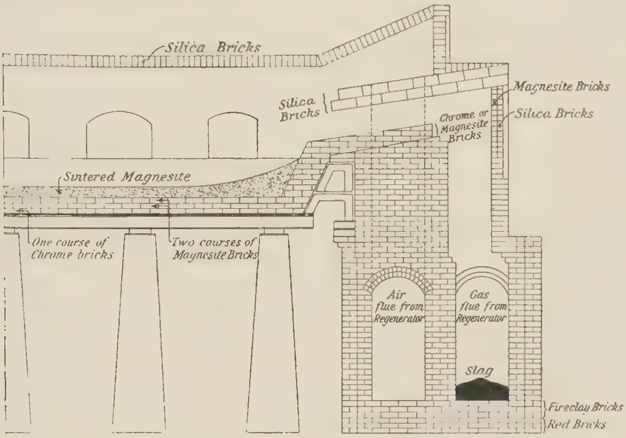


FIG. 150.—Refractory Lining of Modern Basic Open-hearth Furnace.

Relation of Hearth to Capacity of Furnace.—Taking 430 lbs. of liquid steel to equal 1 cubic foot, 5·2 cubic feet will contain 1 ton. The cubical capacity in relation to the output in tons of steel depends upon the length, breadth, and depth of the bath of the furnace. These three dimensions are each important.

(*a*) It is not advisable to have the hearth too short, or the gases which supply the heat will escape before they are properly utilised.

(*b*) The width of the furnace is limited, owing to the difficulty in repairing and patching it between the heats if it is too wide, and also in maintaining a good roof.

(*c*) If the bath is too shallow, losses due to oxidation result.

The third dimension, as a rule, is determined after the length and width are fixed, the product of which give the surface area in square feet. In British practice, the area of the bath for furnaces up to 15 tons is approximately 12 square feet per ton of steel capacity, and 8 to 9 square feet per ton capacity for larger furnaces. For instance, the following sizes of furnaces are typical of British practice :—

Capacity of furnace.	Length of hearth.	Width of hearth.	Area of bed.
			sq. ft.
5 tons.	13′ 0″	5′ 0″	65·0
10 ,,	14′ 9″	8′ 6″	125·37
20 ,,	17′ 6″	9′ 6″	166·25
30 ,,	24′ 0″	11′ 0″	264·0
40 ,,	28′ 6″	11′ 6″	327·75

There are, of course, many furnaces which differ from these dimensions, but the above represents the average practice. The following are some dimensions from American practice :—

Furnace.	Capacity.	Length of hearth.	Width of hearth.	Area of bed.	Area of bed per ton capacity.
				sq. ft.	sq. ft.
Sharon	50 tons	29′ 0″	14′ 6″	420·5	8·4
Laughlin	,,	30′ 0″	15′ 0″	450·0	9·0
Illinois Steel Co. . . .	,,	32′ 0″	14′ 0″	448·0	9·0
Duquesne	60 tons	32′ 0″	14′ 9″	472·0	7·87
Clairton	,,	32′ 0″	15′ 3″	488·0	8·13
Gary	,,	36′ 0″	16′ 0″	576·0	9·6
Lackawanna	75 tons	43′ 6″	16′ 6″	720·0	9·6
Gary	,,	40′ 0″	16′ 0″	640·0	8·53

It will be observed that there are variations in the dimensions, especially in the 75-ton furnace, having an area of 720 square feet, or 9·6 square feet per ton capacity, as compared with the 60-ton furnace having an area of 7·87 square feet per ton capacity. It is not considered advisable to have less than 9 square feet hearth area per ton of steel melted per heat, and about 15 feet should be the limit to the width for successful operation. The curve shown in Fig. 151

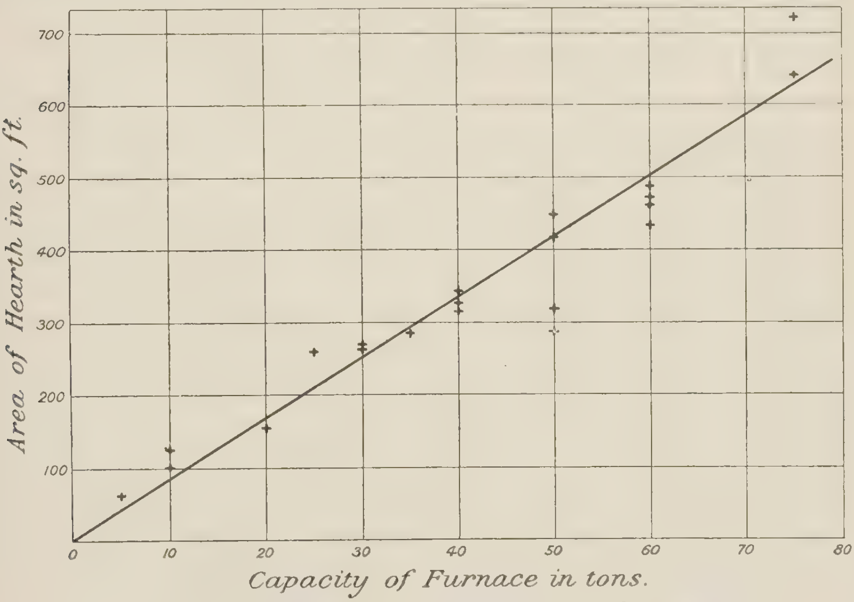


FIG. 151.—Curve showing Mean Value of Relation of Area of Furnace Hearth to Furnace Capacity.

The stars on either side of the curve give the actual relationship of area to capacity of furnaces in operation.

gives a mean value of the area of the hearth in relation to the capacity of the furnace.

Regenerators.—There is no doubt as to the correct position for the regenerators in their relation to the hearth of the furnace. The old method of placing

them directly underneath is not considered at all satisfactory, although furnaces are still found with regenerators in this position. Modern furnaces are invariably built with the regenerators under the charging platform, leaving a good vault between them and underneath the furnace hearth. Fig. 152 shows a modern set of regenerators. Slag pockets, as shown in Fig. 150, are most useful and necessary, and by placing them as shown, the slag can be removed as is found convenient while the furnace is at work, without causing any delay. When slag accumulates it is cut away from the extreme bottom, leaving a layer about 1 foot thick. As more slag accumulates, the cutting away is continued, and so on until the general repair of the furnace takes place, when very little labour is required in removing the remainder of the slag.

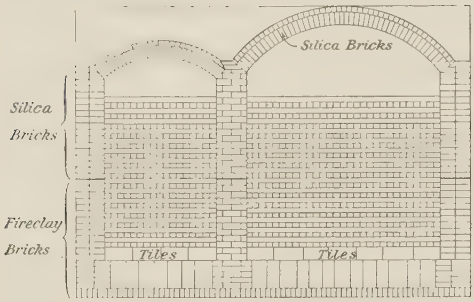


FIG. 152.—Regenerator Chambers and Chequer-work for Modern Open-hearth Furnace.

Capacity of Regenerators.—The relative capacity of the regenerators per ton capacity of the furnace, differs considerably in furnaces in actual practice, as will be seen from the details below, given by E. G. L. Roberts.[1]

Location of furnace.	Size of furnace.	Volume of regenerators.	Volume per ton capacity.
		cubic ft.	
Barrow, England	50 tons	2150	43·0
Illinois Steel Co., U.S.A. . .	,,	4326	86·5
Laughlin, U.S.A.	,,	5628	112·6
Sharon, U.S.A.	,,	6410	128·2

There is a tendency to increase the relative volume of regenerators to the tonnage of the furnace, and the practice in America is to work to about 150 cubic feet per ton of steel output per heat, or an equivalent chequer volume of about 100 cubic feet.

The following sizes are taken from British practice, and may be regarded as typical :—

Size of furnace.	Capacity of each gas chamber.	Capacity of each air chamber.	Total cubic feet per ton capacity.
	Cubic feet.	Cubic feet.	
5 tons	270	400	134
10 ,,	650	850	150
20 ,,	890	1050	97
30 ,,	1270	2150	114
40 ,,	1450	1750	80

Form of Regenerators.—With reference to the relative sizes of the regenerators, the height is considered by many to be the most important dimension. It varies according to conditions of site, and it is difficult to fix

[1] "Iron and Steel Times," June 24th, 1909.

a ratio of height to width per ton of furnace capacity which would be suitable for all sizes of furnaces. It is, however, obvious that if the pathway of the spent gases through the regenerators is short and wide, the chequer-work will not be so likely to receive as much heat as if the width were restricted and the height correspondingly increased. From a number of furnaces in use the approximate relative proportion of the narrowest width to the depth for gas chambers is as 1 : 2, and for air chambers 1 : 1·5.

Chequer-work in Regenerators.—The sizes and quality of the bricks used in regenerator chambers vary. Some users prefer square bricks, and others bricks of rectangular section; in fact, there are many different ways of building the brickwork in regenerators. Fig. 153 (*a*) shows the ordinary method adopted, where square bricks are used, spaced about 3 to 4 inches apart in alternate rows, between which are stretchers or tiles, which are likewise spaced as the

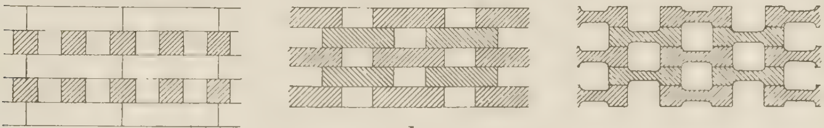


FIG. 153.—Details of Chequer Bricks for Regenerators.

squares, but at right angles to them. Fig. 153 (*b*) shows another method. Bricks $9'' \times 4\frac{1}{2}'' \times 2\frac{1}{2}''$ are placed as shown in plan, and when built up the brickwork is virtually a series of flues $4'' \times 2\frac{1}{2}''$. Fig. 153 (*c*) shows yet another method, in which a specially shaped brick is used, which gives 30 per cent. more air space than bricks shown in (*a*) and (*b*), with the same size of regenerator chamber in each case. Fig. 154 shows the Dietrich form of chequer brick which is used with success in several steelworks in Germany. Silica chequer bricks are sometimes used throughout the chambers, but more frequently only where the heat is most intense, the remainder being of fireclay.

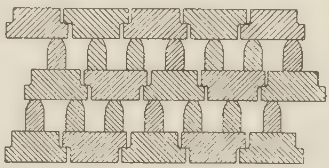


FIG. 154.—The Dietrich Chequer Bricks.

Gas and Air Ports.—Different forms, sizes, and numbers of gas and air ports are found in open-hearth furnaces. They are commonly built up to the main body without forming a part of it, in which case they are bound with separate binders and stays and can be altered and repaired without disturbing the furnace body proper. In modern furnaces the tendency is to make long ports, sloping towards the hearth so as to maintain the direction of the gas and air even when the ports have worn away considerably. Care is also taken in binding the brickwork together, to prevent any possibility of gas and air mixing in the ports before reaching the furnace, due to rents caused by the expansion of the brickwork. When this occurs the ports burn away more rapidly.

In America the use of water-cooled ports is becoming more common, as the trouble, delay, and expense of frequent repairs to the ordinary ports is so considerable. The American silica bricks do not wear so well as European bricks, since they contain more oxide of iron and lime than are found in the latter.

Arrangement of Gas and Air Ports.—This varies very much; the uptakes from the regenerators differ in form and size, but are arranged so that the gas and air mix at the end of the port opening into the furnace hearth. Fig. 150

shows a sectional elevation of a modern port, giving uptakes from the regenerators. The two air flues are made to converge in one opening just above the gas port leading to the hearth of the furnace. Where the furnace is wide the practice is to divide the air port, thus making two air port openings into the furnace, which causes the air to spread more easily over the hearth. The height of the roof has an important bearing in the arrangement of the ports. Roofs are now being made higher than formerly, and without the dip in the crown, which was introduced with the idea of deflecting the flame on to the bath of metal. Many furnaces have more than one gas port at each end, and it is not uncommon to find three gas ports and four air ports, arranged in such a manner as to give equal distribution of gas and air.

Sizes of Ports.—Judging from the sizes of gas and air ports of furnaces in actual practice and apparently doing good work, it is difficult to find a definite relation between the area of the ports and the tonnage capacity of the furnaces. The following average areas of ports in square inches per ton of furnace capacity give an idea of British practice :—

TABLE LXXVIII

AREAS OF GAS AND AIR PORTS

Capacity of furnace.	Gas ports.		Air ports.		Ratio of air to gas ports.	Gas ports. Area in square inches per ton capacity of furnace.	Air ports. Area in square inches per ton capacity of furnace.
	No.	Total area in sq. ins.	No.	Total area in sq. ins.			
5 tons	1	250	2	310	1·24 : 1	50·0	62
10 ,,	2	380	3	620	1·63 : 1	38·0	62
20 ,,	2	510	3	700	1·37 : 1	25·5	35
30 ,,	2	700	3	1050	1·5 : 1	23·3	35
40 ,,	2	1200	3	1600	1·33 : 1	30·0	40

Mr. A. D. Williams, jun.,[1] gives the following sizes of gas and air ports in American open-hearth furnaces :—

Location of furnace.	Gas port area.	Air port area.
	Sq. ft. Sq. ins.	Sq. ft. Sq. ins.
50-ton Laughlin . . .	6·85 = 986·4	18·4 = 2649·6
50-ton Homestead . .	8·0 = 1152·0	18 = 2592
50-ton Duquesne . .	10·5 = 1512·0	18 = 2592
40-ton Homestead . .	8·0 = 1152·0	14·25 = 2052
20-ton Alliance . . .	2·81 = 404·6	12·5 = 1800

If these areas are worked out in relation to the furnace capacity, the following figures are obtained.

Location of furnace.	Gas ports. Area in square inches per ton capacity of furnace.	Air ports. Area in square inches per ton capacity of furnace.
50-ton Laughlin . . .	19·7	53·0
50-ton Homestead . .	23·0	51·8
50-ton Duquesne . .	30·2	51·8
40-ton Homestead . .	28·8	51·3
20-ton Alliance . . .	20·2	90·0

[1] "Iron Age," vol. 76, p. 741.

From British and American practice it is quite clear that no fixed rule is followed in building either the gas or air ports.

Valves.—The valves of an open-hearth furnace perform important duties and require to be well constructed, otherwise much trouble may be caused in operating them, as well as loss of fuel. The air valve is not subjected to the heat that the gas valve receives from the hot gases, and is not, therefore, liable to the same deformation. Many designs of valves are in use, some giving excellent results, while others are faulty and give considerable trouble. Different types of valves are described and illustrated in Chapter XXIX. Perhaps the most important feature of a good valve is its capability of being reversed quickly with a minimum loss of gas.

Sizes of Valves.—The following table gives the average sizes of valves used in open-hearth furnaces in this country:—

Size of furnace.	Gas valve.	Air valve.
5 tons	18″ diam.	18″ diam.
10 ,,	22″ ,,	26″ ,,
20 ,,	28″ ,,	30″ ,,
30 ,,	30″ ,,	33″ ,,
40 ,,	35″ ,,	40″ ,,

The following sizes of gas and air valves, in relation to the sizes of the furnace, are given below (American practice):—

Size of furnace.	Gas valve.	Air valve.
15-ton ———	24″ Butterfly	27″ Butterfly
20-ton Alliance (Ohio) . . .	27″ Forter	27″ Forter
25-ton Wellman Seaver . .	32″ ,,	36″ ,,
35-ton Illinois Steel Co. . .	33″ Mushroom	33″ Mushroom
50-ton Wellman Seaver . .	42″ ,,	48″ Butterfly

Flues.—All furnace flues should be of liberal dimensions to allow for the free passage of gas and air to and from the furnace. They should also be constructed with as few corners as possible to prevent choking and cutting of brickwork. Their length depends upon the location of the gas producers and the regenerators. Some favour very short flues between the furnaces and the gas producers, preferring the gas producers close to the furnace as in the case of the "New-Form" Siemens furnace. Where the gas, however, passes through the gas regenerator chambers as is the general practice in large furnaces, the producers are placed at as short a distance as possible from the reversing valves, depending upon the conditions of site and local facilities for coaling.

Sectional Area of Gas Flue.—The cross-sectional area of the gas flue should be slightly larger than the reversing valve, which determines the amount of gas passing to and from the furnace. One writer[1] gives a rule for the size of gas main in relation to the grate area of the gas producer, *i.e.* one square foot for every 8 square feet of producer grate. This rule could not be applied generally, as the grate areas of different designs of producers are not all the same relative size to output of gas. The area of the flue leading from the reversing valve to the chimney is usually made of very liberal proportions in relation to the size of the reversing valve.

Chimneys.—A good draught is essential to the efficient working of a furnace;

[1] "Iron Age," vol. 76, p. 740.

ample dimensions are therefore necessary. Each modern furnace is fitted with a separate stack, and this is important and advisable in view of efficient control by dampers. Chimneys are rarely built of brickwork entirely, the usual practice being to erect self-supporting chimneys of the type illustrated in Fig. 155. The casing is made of steel plate from $\frac{3}{8}$ inch to $\frac{1}{2}$ inch thick, depending upon the size and height, and is usually lined with firebrick throughout. The casing is supported in a cast-iron bottom ring which rests upon a substantial concrete foundation lined with fireclay bricks. It is usually secured to the foundation with six large bolts, the ends of which are fastened to cast-steel brackets rivetted to the outside of the steel casing around the bottom, making a very reliable structure.

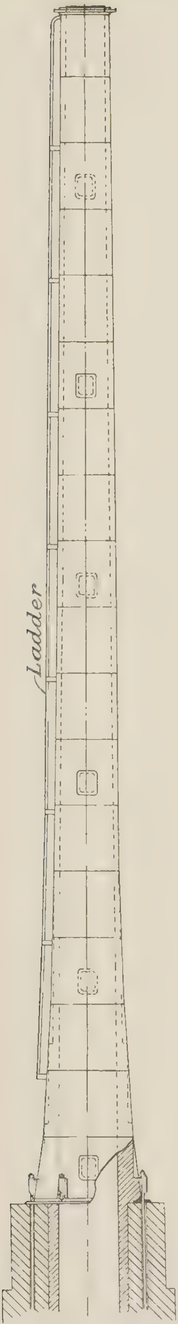


FIG. 155.—Self-Supporting Steel Chimney for Open-hearth Furnace.

Sizes of Chimneys.—Many different rules are given for calculating the cross-sectional area and height of chimneys, which can be found in the numerous pocket and reference books of engineering formulæ. It is not intended to detail these here, but to give actual results from practice. The following give some average sizes of chimneys used in British steelworks practice, which vary considerably in different districts :—

Size of furnace.	Area in sq. feet at base.	Height in feet.
5 tons . . .	·4	60
10 ,, . . .	6	75
20 ,, . . .	8·5	80
30 ,, . . .	10	90
40 ,, . . .	13	100

Below are given the sizes of chimneys used at several American works.

Size of furnace.	Diam. at base.	Area at base in sq. feet.	Height in feet.
15-ton	4′ 0″	12·5	90
25-ton Wellman-Seaver . .	5′ 0″	19·6	125
35-ton Bridgeport, Conn. . .	4′ 8″	17·1	114
40-ton Homestead	5′ 0″	19·6	140
50-ton Duquesne	5′ 6″	23·7	150
50-ton Illinois Steel Co. . .	6′ 0″	28·3	160

Size of Gas Producers for Open-hearth Furnaces.—In deciding what size of producer or producers to instal, the consumption of coal per ton of steel and the size of the furnace are the main factors to consider. If 600 lbs. of coal per ton of steel are consumed, and 50 tons of steel are produced every 8 hours, the total coal consumed in the producer in 8 hours is 30,000 lbs. or 3750 lbs. per hour. Large gas producers are made which are capable of gasifying 30 tons of coal in 24 hours, or $1\frac{1}{4}$ tons per hour, but experience shows that it

is safer and more reliable to base calculations for the size of a gas producer not on the guaranteed output, but on a liberal percentage below the figures given. It is also preferable to have two or three producers grouped together feeding one furnace, rather than to rely upon one large one, which may be stopped for any cause. In the case of the 50-ton furnace referred to, at least two large producers would be required, but it is more usual to find one such furnace coupled to three or four smaller producers.

Grate Area of Producer per Ton Capacity of Furnace.—A rule given for the relative size of producer to the capacity of furnace is 3·5 square feet of producer grate per ton of furnace capacity, but this cannot be taken as a general rule, as all producers do not gasify coal at the same rate per square foot of grate area, and all coal used is not the same quality. In Table LXXIX are given particulars of the grate area of gas producers used for different sizes of open-hearth furnaces.

TABLE LXXIX

PRODUCERS USED FOR OPEN-HEARTH FURNACES

Furnace.	No. and type of producers.	Producer grate area in sq. ft.	
		Total.	Per ton of furnace capacity.
10-ton Rechitza	Siemens	28·4	2·84
15-ton Wellman-Seaver	2 Talbot 10′ 0″	92	6·13
20-ton Alliance, Ohio	—	100	5·0
40-ton Grand Crossing	3 Morgan 10′ 0″	234	5·85
50-ton Illinois Steel Co.	4 ,, 10′ 0″	312	6·24
50-ton Lukens	4 Talbot 10′ 0″	184	3·68
50-ton Ohio	4 Duff 12′ 0″	252	5·04

It will be observed that the producer grate area per ton capacity of furnace varies from 2·84 to 6·24 square feet in the particular cases mentioned. So much, however, depends upon the quality of the coal used and the efficiency of the producer and furnace, that the figures given in the table only convey approximate relationships.

CHAPTER XXVIII

COOLING DEVICES FOR OPEN-HEARTH FURNACES

Ordinary refractory materials of the best quality cannot endure for long the cutting action of the furnace gases. The temperature required for melting and converting the materials into steel, together with the action of the slags, cause the furnace linings to wear more rapidly in certain parts. Perhaps the ports, bulkheads, doors and door jambs of the furnace suffer most. When the ports wear, the roof soon follows, and the cost of repairs then becomes excessive. To increase the durability of the furnace parts which are subjected to the most rapid wear, many cooling devices have been introduced, some of which have given most encouraging results.

Furnace Ports

Solid Ports.—Fig. 156 (*a*) shows a sectional elevation of an ordinary solid port for an open-hearth furnace. Great improvements have been made in their design during recent years, it having been recognised that the angle of inclination of the port to the furnace hearth and the length of the port have an important bearing in prolonging its life and promoting better melting conditions. Fig. 156 (*b*) shows what a port is like when worn. In this condition the efficiency of

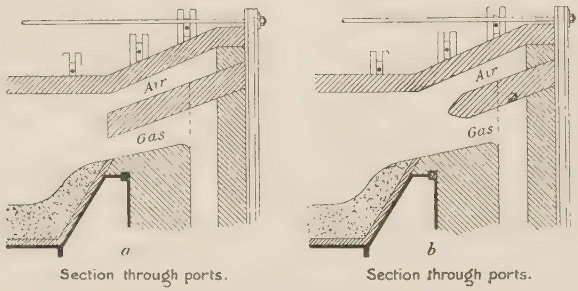


Fig. 156.—Solid Ports for Open-hearth Furnace.
(*a*) When new; (*b*) when worn.

the furnace is reduced, because the direction of the gases cannot be regulated with any certainty. Instead of sweeping down upon the bath of metal, the flame cuts into the brickwork of the roof near to the ports and then passes over the metal and out at the opposite ports, without delivering a proper share of the heat to the contents of the furnace.

Water-cooled Ports.—To prevent excessive wear in ports such as are represented in Fig. 156 (*a*), several kinds of water-cooled ports have been introduced. Fig. 157 illustrates a type which has been used with satisfactory results at the works of the Pennsylvania Steel Co., Steelton, U.S.A. This device was designed

and patented by Luther L. Knox. The port consists of a removable frame, which is placed between the uptake flues from the regenerators and the end wall of the furnace. Fig. 157 *a* shows a front view of the movable port frame in which is built a hollow tank (shown in detail in Fig. 157 *b*), which forms the arch of the gas port and the floor of the two air ports. The tank is built into position with silica bricks, and when finished can be lifted between the furnace wall and uptake flues in a few minutes by means of an overhead crane.

The movable port frame is made of rolled joists and is of very simple design. In Fig. 157 *c* is shown a side sectional view of the frame in which the hollow tank is shown. Water is circulated through the tank by inlet and outlet pipes. The inlet pipe extends right across the face of the inside of the tank nearest the surface most exposed to the hot gases. Streams of water at a pressure of 12 to 40 lbs. per square inch issue through perforations in the pipe on to the inside surface of the tank, and leave by the outlet pipe at the same end but at the back side of the tank. A "blow through" pipe is arranged for the periodic removal of sediment. Pipe connections are conveniently placed beside the furnace so that the joints can be made in a few minutes after the movable port frame is placed in position.

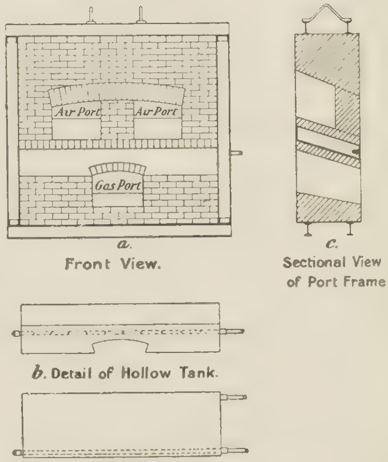


FIG. 157.—First Development of the Knox Patent Port.

Between the removable port frame and the furnace wall are placed hollow castings about 6 inches to 8 inches wide, through which water circulates. They

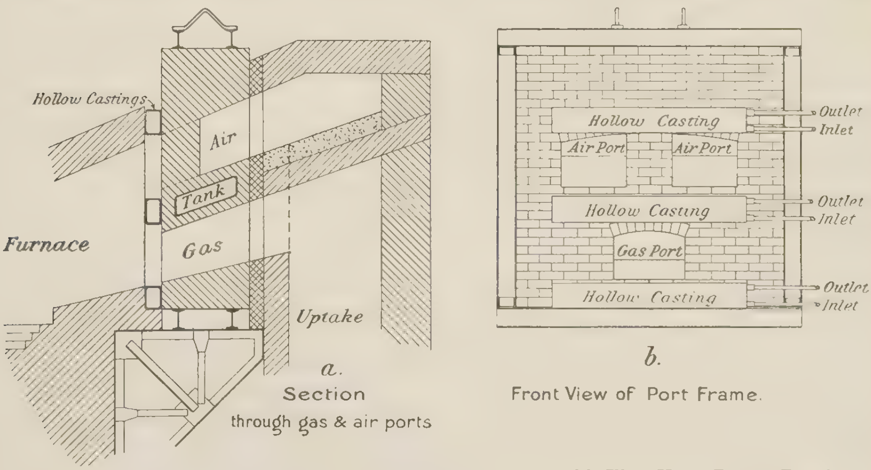


FIG. 158.—Carney and McEntee's Water-cooled Frame with First Knox Patent Port in Position.

extend across the face of the wall where the cutting action of the gases, issuing through the ports, is most severe upon the brickwork. Fig. 158 *a* shows the removable port frame in position, and Fig. 158 *b* shows the end wall of the

furnace with the arrangement of hollow castings. The remaining space between the frame and the furnace is built up with loose bricks, fireclay and sand.

The Knox Pressed Steel Port.—The Knox port, as shown in Fig. 159, is

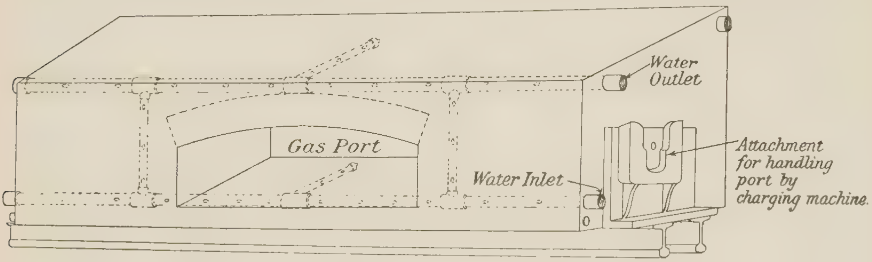


FIG. 159.—The Knox Pressed Steel Water-cooled Port.

an improvement on the original port, and is arranged so that no end wall cooling

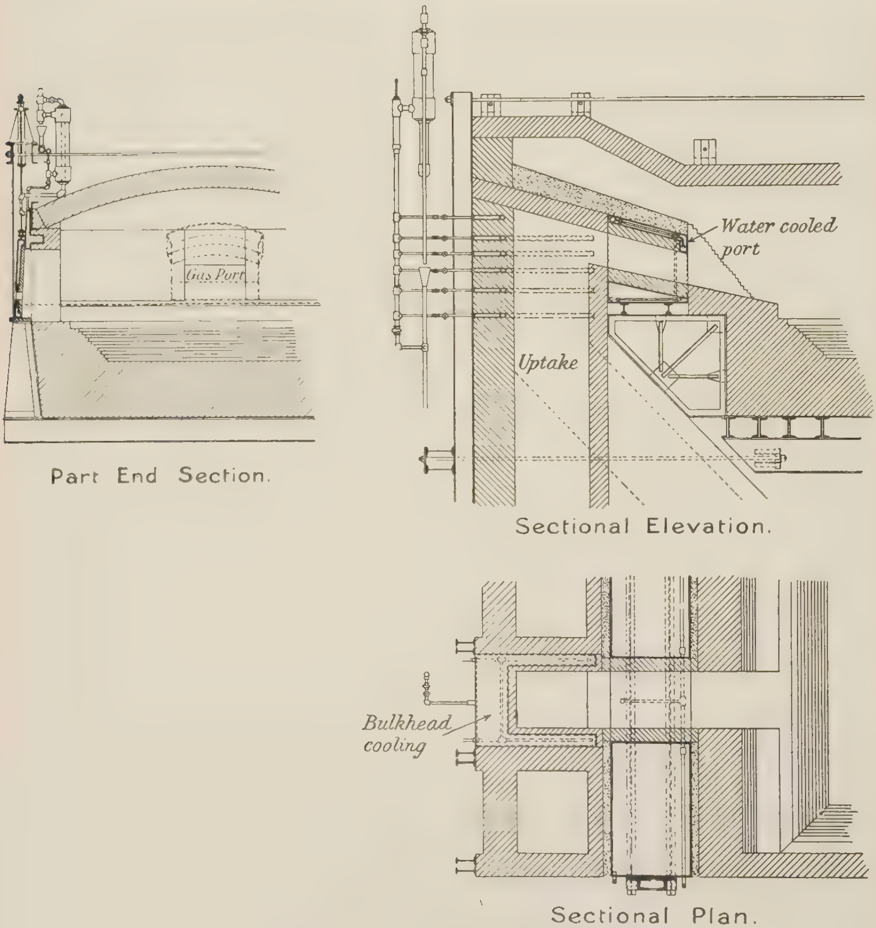
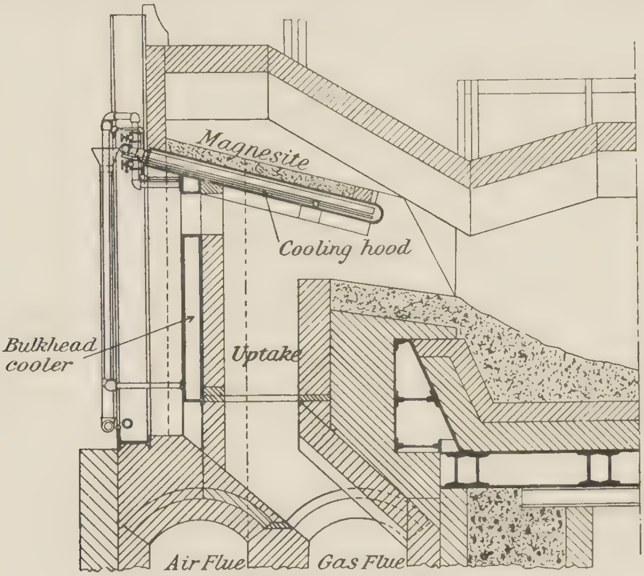
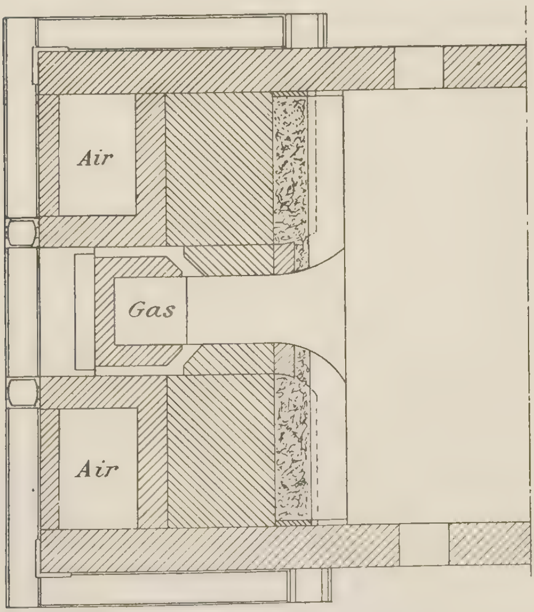


FIG. 160.—Knox Water-cooled Gas Port and Bulkhead.

is required. Fig. 159 shows the Knox port, which is built into a movable frame in a similar manner to the port already described. The Knox improved



Sectional Elevation.



Sectional Plan.

FIG. 161.—The Blair Water-cooled Port and Bulkhead.

port, however, differs in form from the original port, as the whole gas port,

and not only the arch is surrounded by the frame. The hollow tank is made of rolled steel plates about $\frac{3}{8}$ inch thick, welded at the joints. Being made of thin plates, it is a rapid cooling medium. In Fig. 159 the arrangement of the inlet pipes is shown. In these pipes perforations are made, so that water may issue upon the parts most exposed to the flame. When the movable port frame is put in position, as shown in Fig. 160, the joint between it and the furnace wall is made good by ramming it with sand. When in the U.S.A. in 1912, we had the opportunity of witnessing both the above ports at work on furnaces of capacities ranging from 60 to 100 tons, and were informed by those who had used the Knox ports for some time that the following saving was effected :—

Saving in Repairs.—In one installation of furnaces in Pennsylvania where water-cooled ports of the Knox type have been introduced, it was found that the ports required no attention until the general repairs to the furnace were undertaken. Prior to the introduction of the water-cooled ports, the solid bricked ports had to be repaired after every 35 to 40 heats. The saving effected in repairs to the furnace has been from 30 to 35 per cent., and the tonnage has increased from 18,000 to 22,000 tons per month. As the result of being able to work the furnace for longer periods without shutting down for repairs, not only are the costs of repairs reduced, but also those of fuel and labour, and consequently the total cost per ton of steel.

The Blair Port.—The Blair port consists of a water-cooled boiler plate hood of simple construction, which takes the place of the ordinary gas port arch and rests on each side of a magnesite bank forming the sides of the gas port. The underside of the water-cooled hood is exposed to the flame, but the joints of the plate are made on the top face which is covered with ground magnesite to a depth of about 5 inches and protects the seams from any contact with the flame. The covering of magnesite has proved to be far more efficient in resisting the cutting action of the flame than silicious brickwork, owing to the magnesite being a better conductor of heat.

Bulkhead cooling is also carried out in a similar manner to that adopted for cooling the arch. A box or tank is fitted into the brickwork, through which the return of water from the cooled arch of the gas port circulates. Fig. 161 shows sectional elevation and plan of a furnace end with water-cooled gas port arch and bulkhead.

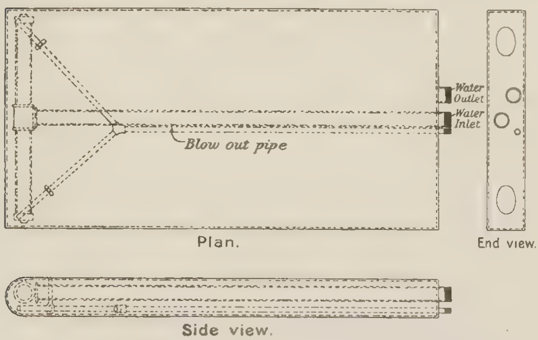


FIG. 162.—Details of Blair Cooling Hood for Gas Port.

Fig. 162 shows details of the gas port arch with a 3-inch water supply pipe passing down the inside of the port, at the end of which a cross Tee pipe is fitted. This pipe is perforated with small holes through which streams of water flow at a pressure of 9 lbs. per square inch. Another pipe, $\frac{3}{4}$ inch in diameter (shown in Fig. 162), is used in the cooling arch for scouring out deposits of sludge which tend to gather at the extreme end of the hood. A high pressure of water is used for this purpose.

The Blair cooling devices have been fitted to several furnaces in the United States and Canada, with most satisfactory results. They are also being fitted to

furnaces in this country. The Blair ports were first introduced at the Lackawanna Steel Co. in 1907, being fitted to two 60-ton fixed open-hearth furnaces, Nos. 7 and 8. In 1907, 266 heats from the port and roof, and 403 heats from the regenerators of one furnace were obtained before repairs were necessary. Before the Blair ports were fitted, the number of heats obtained were as follows: 133, 143, 167 and 170, or an average of 153. These results were obtained from No. 7 furnace. From No. 8 furnace, 592 heats were obtained before shutting down for repairs, 37,772 tons of ingots being produced during the campaign. The superintendent of the open-hearth plant stated that during that period there was an average fuel consumption of 448 lbs. per ton against 600 lbs. per ton of ingots previously. The total cost of repairs during the campaign of $8\frac{2}{10}$ months was £1279, or approximately 8*d.* per ton of steel produced.

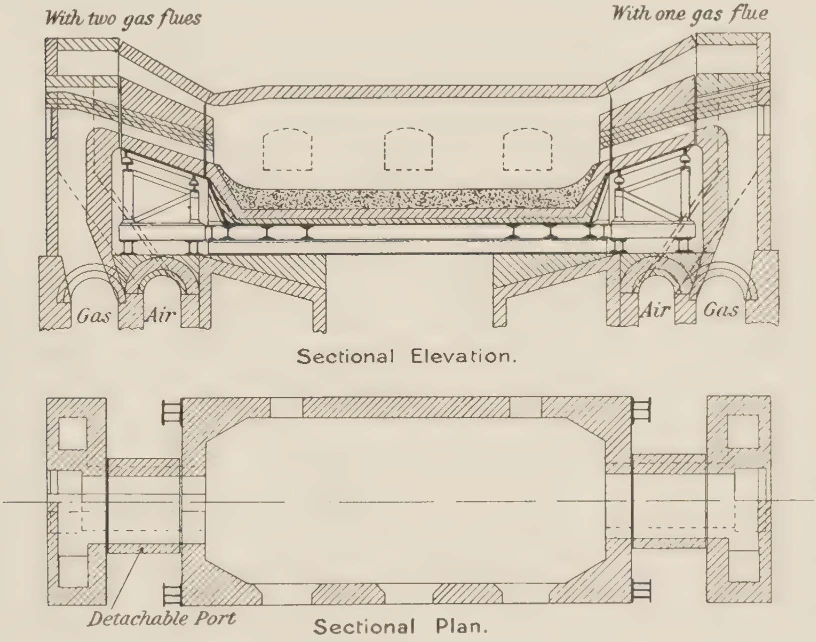


FIG. 163.—The Friedrich Detachable Port.

The Friedrich Detachable Port.—Fig. 163 shows views of the Friedrich detachable port which is used with the same object as those already described. It will be observed from the illustrations that the detachable port fits between the end wall of the furnace and the uptake flues from the regenerator. The ports are so arranged that they can be removed without disturbing the surrounding brickwork of the furnace, thus prolonging the life of the flues and making the furnace more efficient. The port can be lifted out of position by means of an overhead crane, or it may be drawn out on a truck from the side. At the Julienhütte works in Germany, the ports have been in successful operation for some time, and have effected a considerable saving in repairs, and increased the output of the 40-ton furnace to which they are fitted.

Cost of Installing and Saving effected.—The weight of a detachable port

for a 40-ton open-hearth furnace is about 9 tons, and the following are the details of cost :[1]—

	£	s.	d.	
Firebrick	28	10	0	This is the cost each time a port is replaced.
Bricklayers' wages	4	0	0	
Cost of fitting	4	10	0	
Mechanics' wages	1	10	0	
Total	£38	10	0	

	£	s.	d.	
Two cast-steel plates	60	0	0	These costs are only incurred once.
Bracings for the air flue vault, including materials and labour	3	10	0	
Stays, including materials and labour	5	0	0	
Total	£68	10	0	

TABLE LXXX

COMPARATIVE PRICES OF SOLID AND DETACHABLE PORTS, FRIEDRICH TYPE

The following relate to a 20-ton furnace before and after using the Friedrich port.

	With fixed ports.			With Friedrich detachable ports.		
	Weight in tons.	Price per ton.	Total cost.	Weight in tons.	Price per ton.	Total cost.
		£ s. d.	£ s. d.		£ s. d.	£ s. d.
Silica	123·5	1 18 8	238 17 0	92·2	1 18 8	178 5 0
Silica mortar	11·8	1 10 7	18 0 0	8·8	1 10 7	13 10 0
Magnesite	3·0	6 12 4	20 3 0	—	—	—
Magnesite mortar	0·3	4 17 9	1 9 0	—	—	—
Brickwork	132·0	1 0 4	135 0 0	98·2	1 0 4	100 0 0
Ties	4·6	15 6 0	70 4 0	2·3	15 6 0	35 11 0
Rolled iron	13·0	7 13 0	99 0 0	9·6	7 13 0	73 10 0
Cooling boxes, trestles, etc.	15·3	8 3 0	125 4 0	—	—	—
Cast-steel plates	—	—	—	2·8	15 6 0	43 10 0
Angle stays, stay bars, etc.	—	—	—	3·1	8 3 0	25 12 0
Box girder (wrought iron)	—	—	—	2·5	10 3 8	25 0 0
Old rails	—	—	—	0·5	5 1 10	2 10 0
Vault caps	—	—	—	0·98	12 14 6	12 10 0
Wheels, axles, bearings, etc.	—	—	—	1·2	15 6 0	18 15 0
Erecting	33·0	0 15 3	25 3 0	23·0	0 15 3	17 13 0
Total	—	—	733 0 0	—	—	546 6 0

Difference in cost, £186 14 0

The Head Detachable Port.—Fig. 164 shows a simple arrangement of movable port devised by Mr. B. W. Head. The structure rests upon a frame

[1] "Iron and Coal Trades Review," vol. 82, p. 880.

supported upon a truck, a sealing frame being raised to clear it from the water-seal round the joint of the uptake flue when it is desired to remove the port from the furnace.

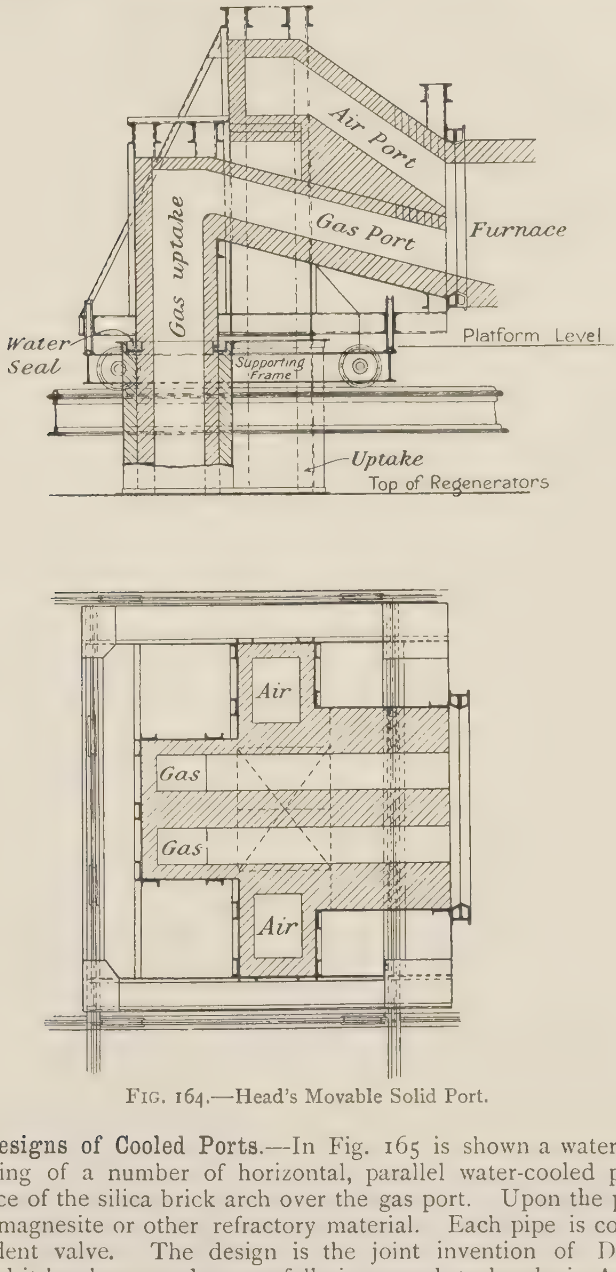


FIG. 164.—Head's Movable Solid Port.

Other Designs of Cooled Ports.—In Fig. 165 is shown a water-cooled gas port consisting of a number of horizontal, parallel water-cooled pipes, which take the place of the silica brick arch over the gas port. Upon the pipes is laid an arch of magnesite or other refractory material. Each pipe is controlled by an independent valve. The design is the joint invention of Davison and Mathies,[1] and it has been used successfully in several steelworks in America.

[1] "Iron Age," vol. 75, p. 1436.

Another very similar type of port (see Fig. 166) installed at the Minnequa works of the Colorado Fuel and Iron Co., by F. E. Parks and H. A. Devel,[1] consists of a series of 2½-inch pipes brought in over the bottom arch of the gas port. These pipes end in a bronze block which forms a solid arch at the inside

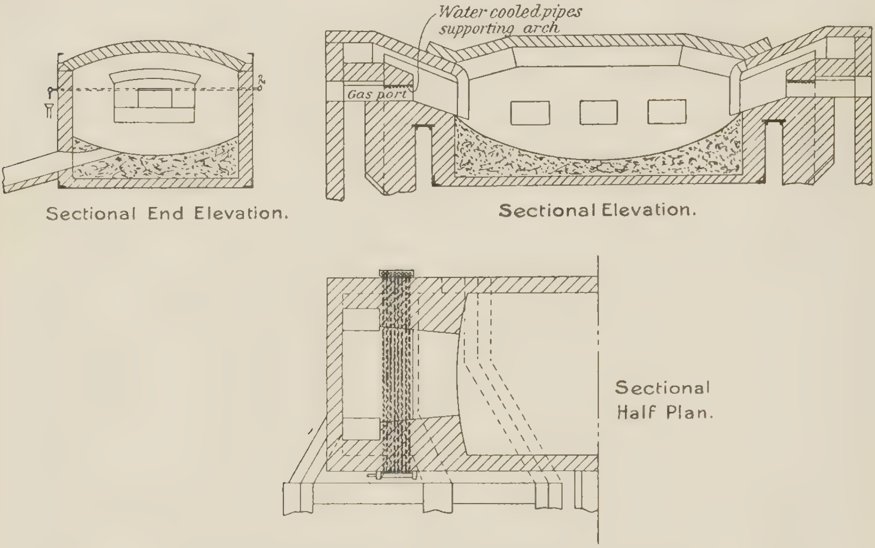


FIG. 165.—Davison and Mathies Water-cooled Gas Port.

of the port. At each side is a skew-back bronze casting which supports this arch should the brick arches burn out or fall; they also prevent the ports from burning out on the sides. The supply water is brought in by a 1-inch pipe

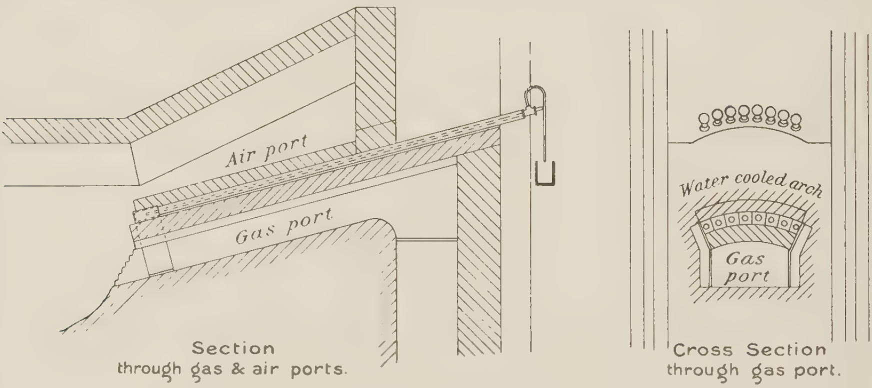


FIG. 166.—Parks and Devel Water-cooled Arch.

which runs within a few inches of the end of the bronze block. Several furnaces have been equipped with this device. The average cost of installation is about £100, which includes all labour and material.

Water-cooled Doors and Frames.—It is many years since water-cooled doors were first fitted on open-hearth-furnaces, although some furnaces of 30 or

[1] "Iron Age," vol. 82, p. 1063.

40 tons capacity can be found with the old-fashioned heavy cast iron doors lined with brickwork. Most of the furnaces which are fitted with water-cooled doors use the cast iron water-jacketed type, which are very cumbersome and heavy and are also liable to crack readily. Within the past two years pressed steel doors and frames have been introduced, through which water is caused to circulate for cooling the doors and jambs of the furnace. From the results obtained they appear to be giving entire satisfaction. Whilst visiting steelworks in the Pittsburg and Cleveland districts, we observed the ease with which the melter could examine the condition of the furnace through the peephole of the door without the slightest discomfort. On the door of a 75-ton furnace it was possible to place one's hand for an instant without injury.

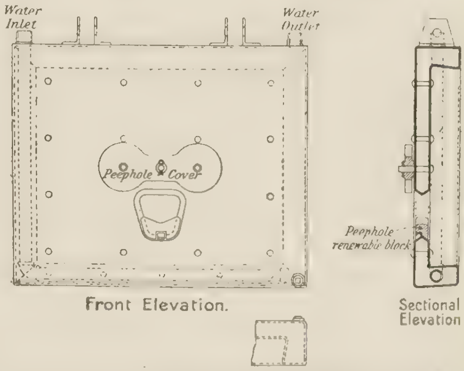


FIG. 167.—Knox Pressed Steel Water-cooled Door.

Fig. 167 shows the pressed steel door made of material about $\frac{1}{4}$ inch thick. It differs from the cast iron door in the thickness of the material, and in having a renewable block in the peephole through the door, which takes the wear of the bar used by the furnacemen.

In one large steelworks in Pittsburg where cast iron and pressed steel water-cooled doors were used, we were informed by the steel superintendent that one pressed steel door lasted as long as 4 to 5 cast iron water-cooled doors. The material of the cast iron doors is about 1-inch thick in section, and the cooling action of the water does not rapidly penetrate the material. Fig. 168 shows details of water-cooled door frame.

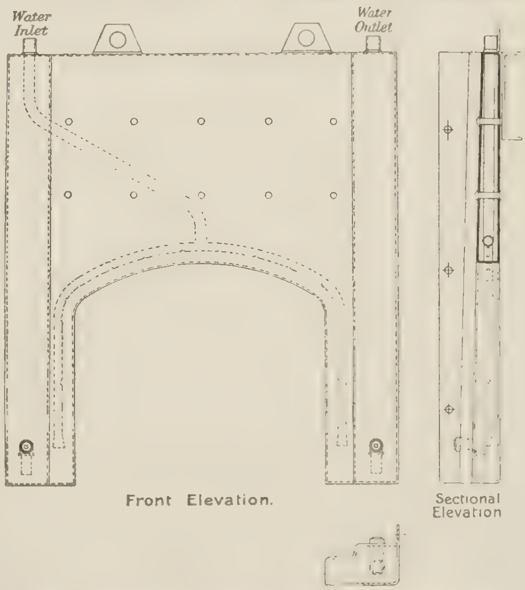


FIG. 168.—Knox Pressed Steel Water-cooled Door Frame.

Fig. 169 shows the arrangement of the Knox patent pressed steel water-cooled doors and frames on the front of a furnace fitted with three doors. The frames are secured to uprights in a simple manner and the doors are lifted hydraulically. Flexible pipe connections are made at the doors to allow for their movement. The circulation of the water through the doors and frames proceeds from an overhead tank above the furnace, the water being forced down through an ejector in the bottom of the tank and passes through the doors and frames and back to the

tank, which is always kept full of water. The details of the pipes in the doors and frames are shown in Figs. 167 and 168.

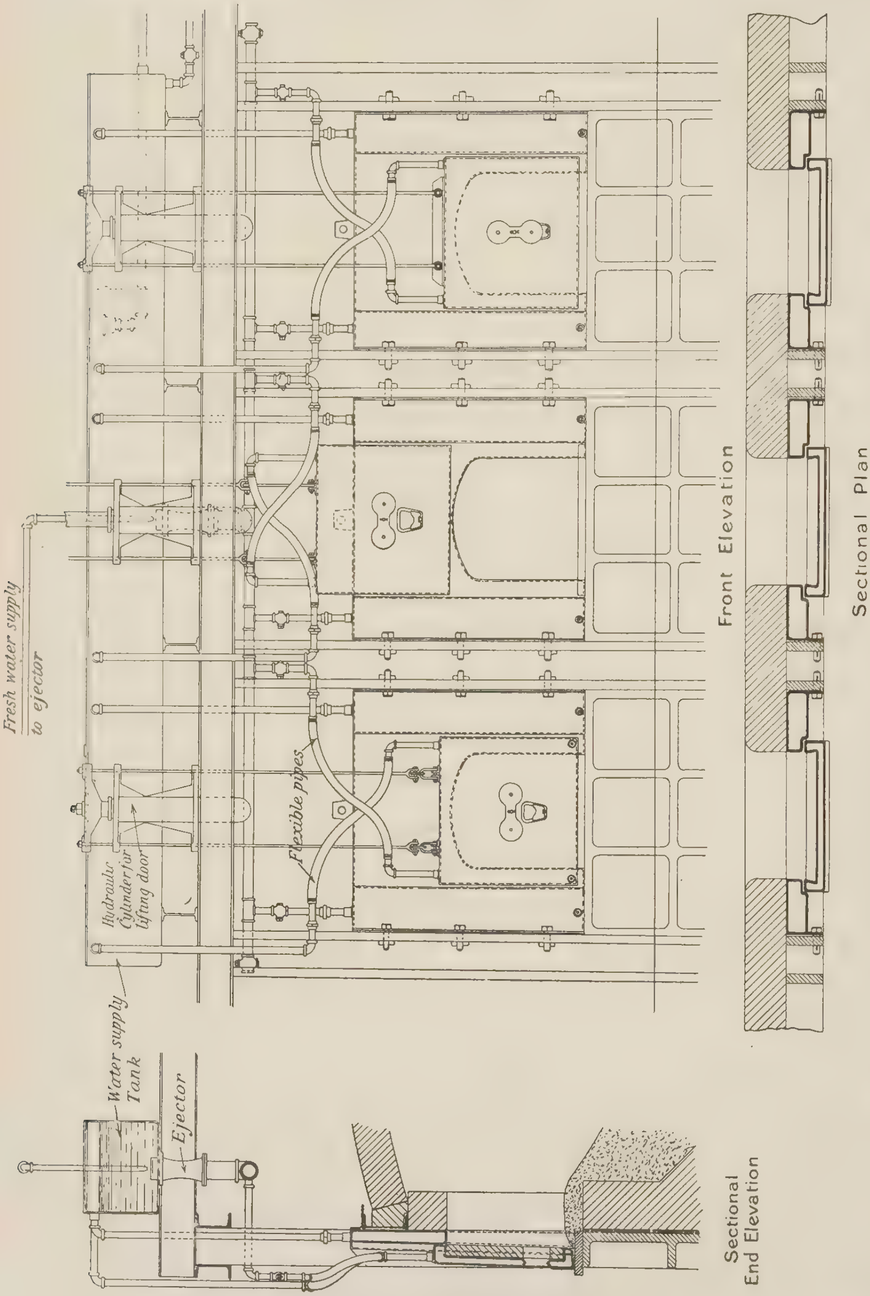


FIG. 169.—Arrangement of Knox Patent Water-cooled Doors and Frames on Open-hearth Furnace.

Bulkhead Cooling.—There is considerable difficulty in keeping the bulk-

heads of furnaces in repair, owing to the cutting action of the flame as it passes over the ports and strikes against the back wall of the uptake, or what is known as the "bulkhead." At the Gary works, Illinois, where they have probably the largest open-hearth plant in the world, they have found that water-cooling has been useful in reducing the cost of repairs. They introduced pipes of rectangular section fitted between every 3 or 4 tiers of bricks in the end wall. A constant flow of water was passed through them, cooling the surrounding brickwork.

In Fig. 160 the arrangement for cooling the bulkheads as devised by the Knox Pressed and Welded Steel Co., shows six U-shaped chambers of rectangular section containing pipes with small perforations, and arranged to keep a constant spray of water on the surfaces most exposed to the heat.

CHAPTER XXIX

VALVES FOR OPEN-HEARTH FURNACES

THE subject of valves is an important one in the economical and efficient working of an open-hearth furnace. For regulating the supply of gas and air, inlet valves are fitted, which are usually of the ordinary mushroom type, as shown in Fig. 171. The difficulties met with in working reversing valves have led to the development of several types of valves, designed with the object of minimising the leakage of gas, and allowing reversals to be carried out expeditiously and with a minimum of manual labour.

Siemens' Reversing Valve.—For many years after the introduction of the open-hearth furnace, the type of valve commonly used was the Siemens' butterfly valve, which to this day is employed extensively in its improved form. Fig. 170 gives a part sectional view of the arrangement. The casing is of cast iron

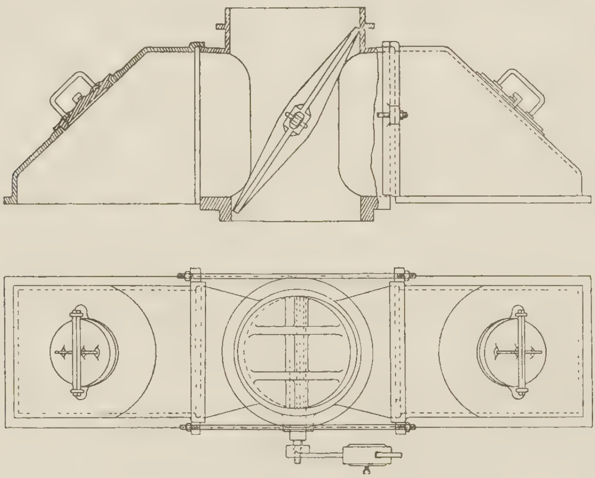
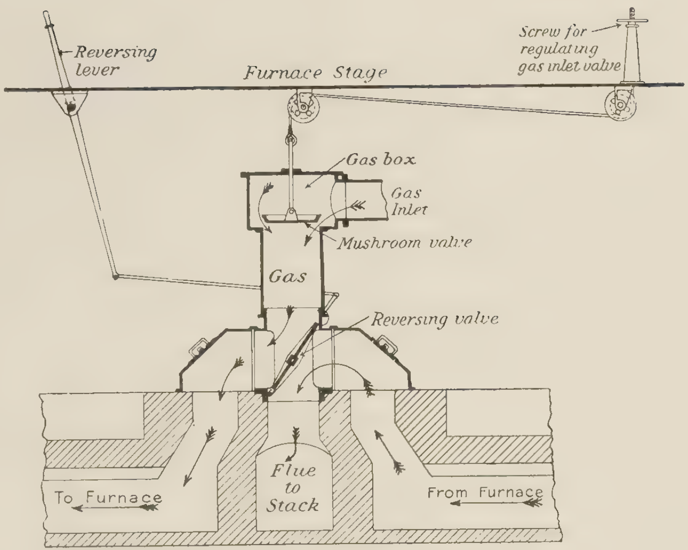


FIG. 170.—Siemens' Reversing Valve.

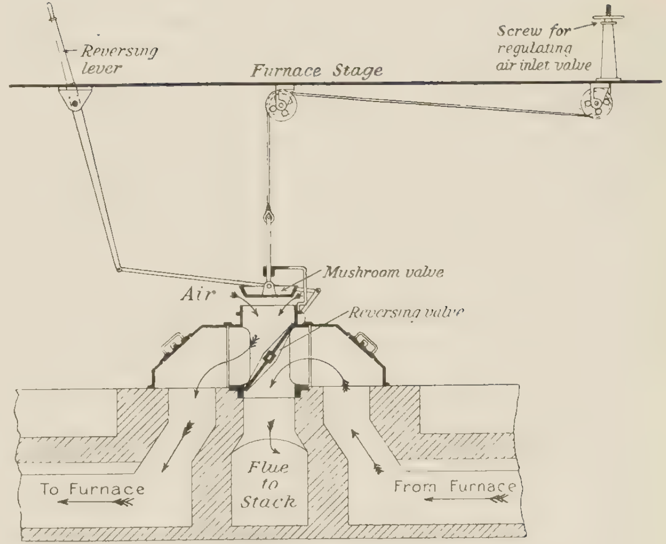
or cast steel, the opening at the top being connected to the gas or air supply. The valve is supported on a spindle, by means of which it can be thrown over from one side to the other by a suitable arrangement of levers from the furnace stage.

Fig. 171 shows the ordinary arrangement of gas and air reversing valves with inlet valves and operating gear.

Kirkham's Improved Valve.—With the object of reducing the leakage of gas, William Kirkham, of Sheffield, introduced a valve with a flap or "tongue," in two portions, as shown in Fig. 172. A small movement of the upper portion, on the spindle, allows the valve to adjust itself to the casing. There



Sectional Elevation.
Gas Reversing Valve.



Sectional Elevation.
Air Reversing Valve.

FIG. 171.—General Arrangement of Gas and Air Reversing Valves.

is less liability to warp with the Kirkham than with the solid valves. The tongues or flaps also can be readily renewed when worn.

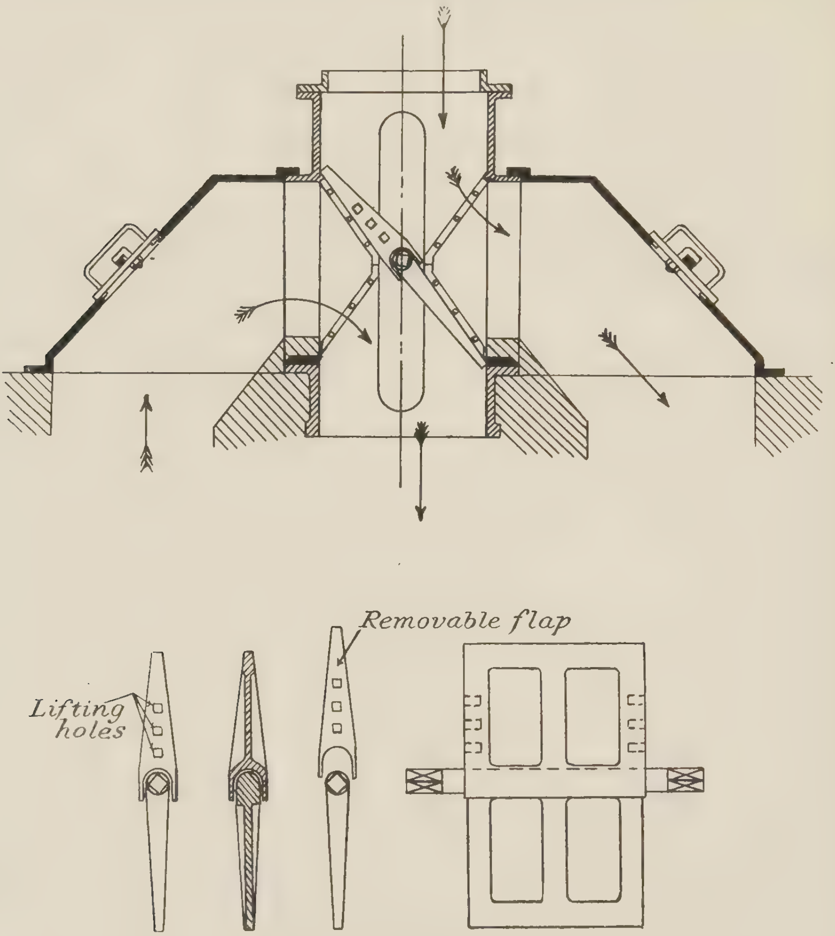


FIG. 172.—The Kirkham Valve.

The Schild Valve.—This valve consists of a heavy cast iron plate in which are three holes corresponding with the openings of the gas and chimney flues, and on this plate slides a pan having four openings through it. The two middle openings in the pan are covered by a hood forming a passage for the waste gases, and the two outer openings are connected by a U-shaped pipe. Fig. 173 shows a sectional elevation of the arrangement. On top of the U-shaped pipe is another pan with a hole in it, through which the gas passes into the pipe leading to the flue. Both pans are filled with water, the upper one forming a seal between the gas box and the pipe, and the lower one keeping the bottom plate cool. By means of a hydraulic cylinder and ram, the lower pan with its hood and pipe is moved across the openings in the bottom plate, thus reversing the direction of the gases. The air valve is constructed in a similar manner, but is simpler, and has no stationary box.

Since the introduction of this reciprocating valve, the principle has been

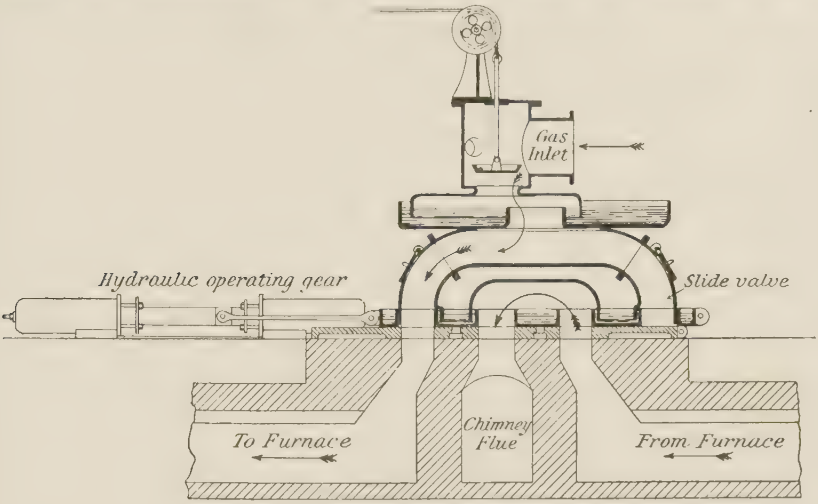


FIG. 173.—The Schild Valve.

applied to a rotating valve. This latter valve is mounted on a stationary base-

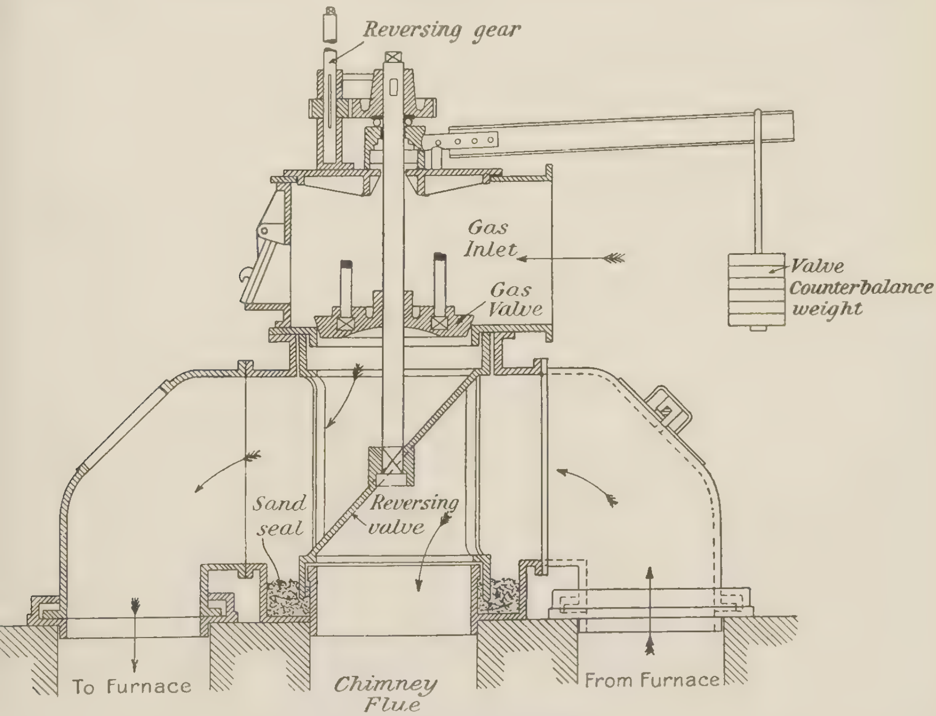


FIG. 174.—The Fischer Valve.

plate containing three openings at 120°, two of which communicate with the

gas flues leading to the regenerators, and the third with the flue leading to the

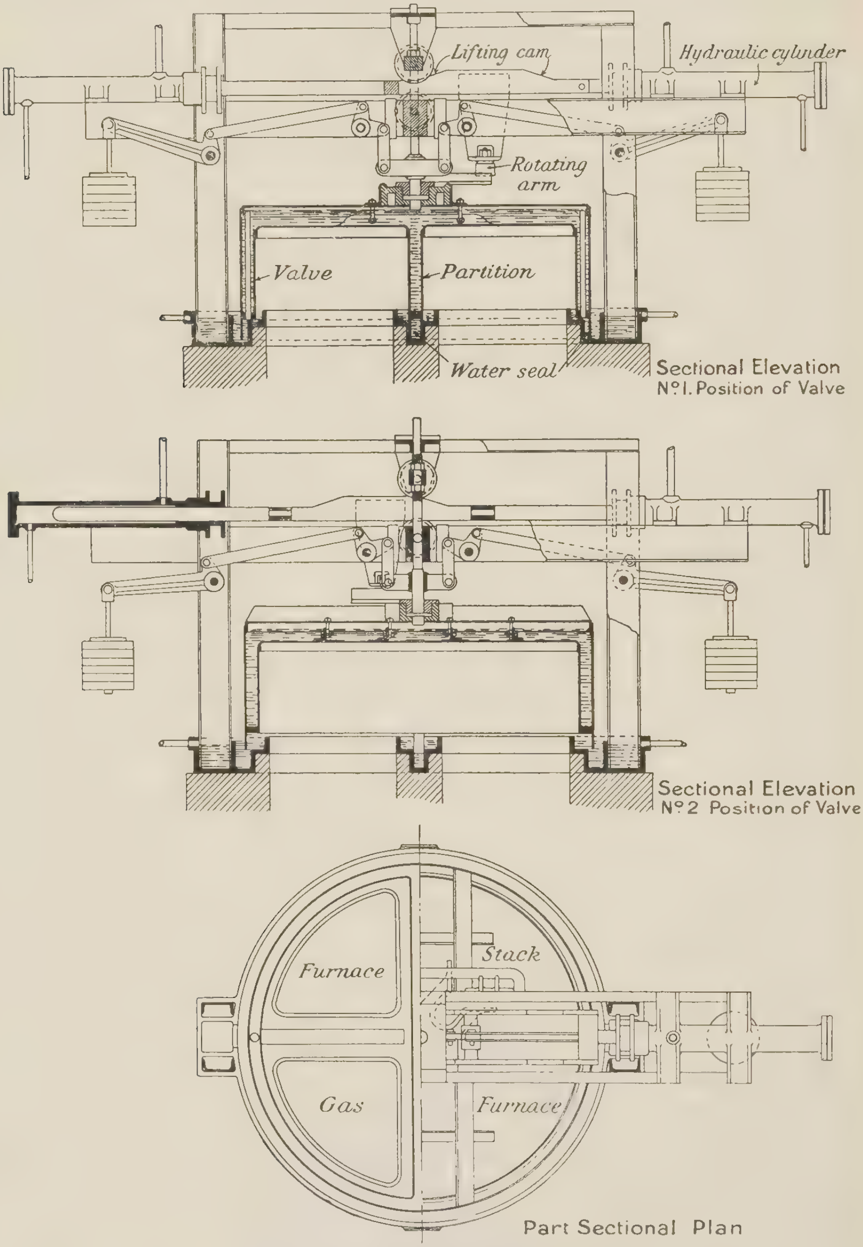


FIG. 175.—The Dyblie Reversing Valve.

stack. A pan with three openings corresponding to those in the bedplate rests upon the latter, two of the openings being covered by a connecting hood, and

the third by a pipe forming the gas supply flue. To the circumference of the pan is secured a toothed rim, by which the pan can be rotated.

The Fischer Valve.—This consists of an inner cylinder with a diagonal partition, working inside a valve casing of the ordinary Siemens type. The partition in the cylindrical valve isolates the passage connecting the gas flue with the furnace from the passage connecting the furnace with the stack, and by half a turn of the valve, the diagonal partition reverses the direction of the flow of the gases. The joint between the valve and the casing at the top is maintained by means of a balance weight. The joint at the bottom, between the valve and the casing, is made by a seal of sand or asbestos. Leakage of gas at the circumference of the valve is prevented by sealing strips and segments which are adjusted by means of counterweights. The weight of the valve is taken by a ball bearing, and the valve can be reversed by hand. Fig. 174 shows the arrangement.

The Dyblie Valve.—Sectional elevations and plan of this valve (made by the Morgan Construction Co.), are shown in Fig. 175. As will be seen from the illustration, the furnace, stack, and gas or air flues terminate in a group of four openings forming quadrants of a circle. Over these flue openings is placed a hollow cylindrical valve having a diametrical partition inside, dipping into a water-sealed casting on the brickwork flue. The reversal of the valve is made by raising it sufficiently (by means of the hydraulically operated lever gear shown) to permit the centre partition to clear the edges of the water-seal; the depth of the centre partition being made less than the circumference of the valve, the water-seal is not broken when the valve is reversed. The valve itself is surrounded by an outer cylindrical box open at the top, filled with water and forming a water-jacket.

The Blair Reversing Mechanism.—This device consists of swinging sections of flues which can be made to connect the gas and air supply to either end of

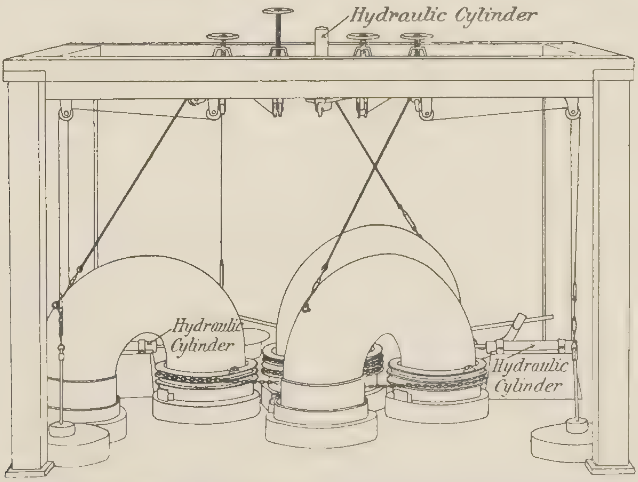


FIG. 176.—Blair Reversing Mechanism, showing tubes in position, and Operating Gear.

the furnace, and the waste gases to the stack, without the introduction of valves. Fig. 177 shows a plan of gas and air flues, and Fig. 176 the arrangement of the Blair swinging flue sections. The sections are constructed of steel plates lined with firebrick, and their ends dip into water-seals. To reverse the furnace, the gas-regulating valve is closed by means of a hydraulic cylinder, which at the

end of its stroke releases the valve actuating a second cylinder, and lifts the ends of the three flue sections out of their water-seals. At the end of the stroke of this cylinder, the valve operating a third cylinder is actuated, which causes the three tubes to swing round. The second cylinder is then operated,

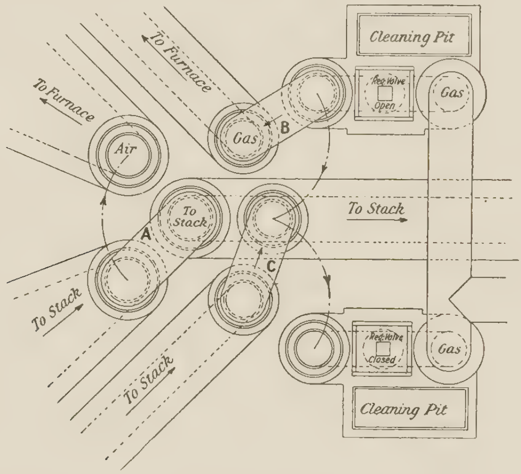


FIG. 177.—Plan of Blair Reversing Mechanism.

Tube A connects either end of furnace to stack alternately, leaving the unconnected flue open for admission of air to furnace. Tubes B and C connect alternately, the gas valves with furnace and furnace with stack.

and the tubes are lowered into their reversed positions in the water-sealed cups at the tops of the flues. The other gas-regulating valve is now opened, and the working of the furnace proceeds. The gas and air regulating valves are automatically adjusted to the positions they occupied during the previous period of operation.

CHAPTER XXX

MIXERS

PRIOR to 1889, when Captain Jones, in America, and Mr. G. Hilgenstock, in Germany, simultaneously introduced the mixer into steelworks practice, liquid metal for Bessemer converters was either taken direct from the blast furnace, or from cupolas where the pig iron was remelted. Irregularity in the quality and rate of output often resulted from the use of metal taken direct from the blast furnaces, as variations in the composition of the iron were not uncommon, and delays were sometimes occasioned in the supply of the hot metal to the converters. Remelting in the cupola remedied to some extent both these defects, but the cost of remelting and the impartation of more sulphur to the metal during the process, increased the cost of production without improving the quality of the material, which, however, was more regular in composition.

The first mixer used on the Continent was of 70 tons capacity, and erected at Hoerde in 1889.[1] In the same year a mixer of 80 tons capacity was installed in England at the Barrow Steelworks. Mixers were used in Bessemer steel manufacture only until about the year 1900, when the use of fluid metal for ordinary open-hearth charges was developed. With open-hearth furnace plants, the mixer is becoming increasingly useful, both for acid and basic fixed furnace practice as well as for the various continuous processes conducted in fixed and tilting open-hearth furnaces.

The mixer was first applied in steelworks as a collector of the various charges from the blast furnaces, unifying the composition of the metal and serving out the furnace charges as required. Since then it has developed into a huge furnace, equipped with regenerators and fuel supply apparatus, performing the functions of collector, purifier, and distributor. It is fast becoming an important installation in all modern steelworks.

Design of Mixers.—There are several designs of mixers, and a few of them are illustrated[2] in Figs. 178 to 183 which follow. One of the simplest forms of mixer is that illustrated in Fig. 178. It consists of a cylindrical casing with eccentric conical nose resembling a Bessemer converter, with inlet and outlet for the metal. In the sectional views the lining is shown. This type of vessel is operated by hydraulic power in the same way as the mixer shown in Fig. 179. It is not, however, heated by gas or other means, but acts merely as a collector and distributor of metal.

Converter Type of Mixers.—In Fig. 179 are shown a sectional elevation and cross-section of a mixer used as a collector of metal, in which the iron is kept hot by means of oil fuel and air under pressure. The form of the vessel is similar to that illustrated by Fig. 178, having a cylindrical body with conical nose. It has an inlet near the bottom on the top side, and an outlet at the nose. Both openings are covered with hinged doors, operated electrically by motors, arranged as shown in the illustration. Beyond the metal inlet

[1] "Journal Iron and Steel Institute," 1891, II, p. 761.

[2] By the kind permission of the makers, Messrs. The Berlin-Anhaltische Maschinenbau-Actien-Gessellschaft, Köhn-Bayenthal.

there is an outlet on the top of the mixer for gases which arise from the metal. These are carried away through a flue which is connected between the outlet on the mixer and the trunnion joint fixed to the pedestal in line with the centre

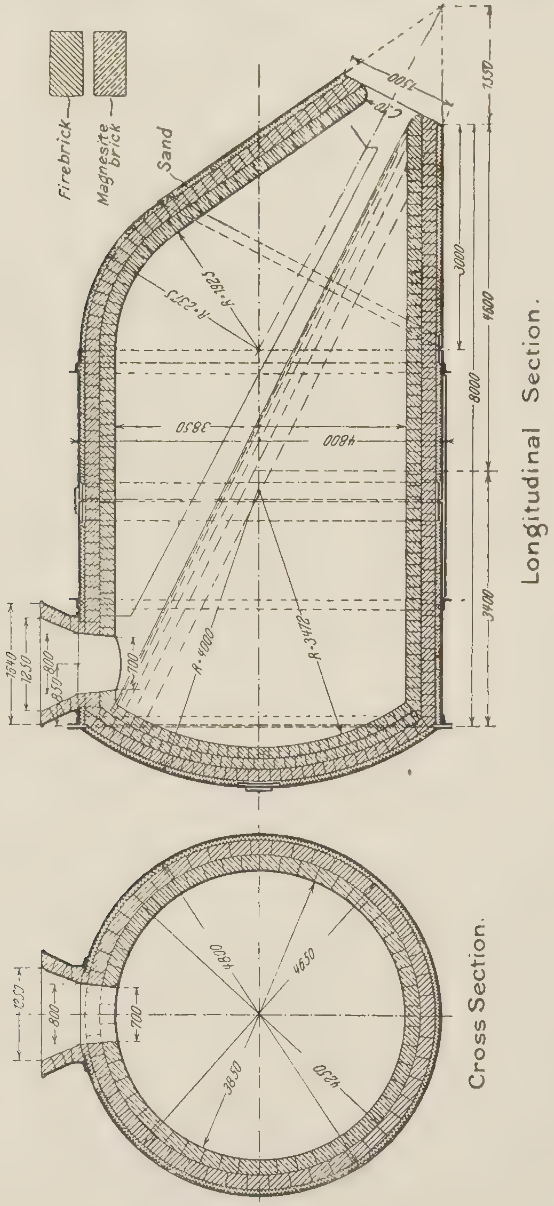


FIG. 178.—Converter Type of Mixer, showing lining.

of the rocker, upon which the mixer tilts. There is also an oil or gas fuel inlet near the nose of the mixer. The tilting of the mixer is performed by a hydraulic cylinder with ram attached to a connecting link, which engages with

a bracket bolted to the end of the mixer. This is shown clearly in Fig. 179. The movement of the mixer is limited by a bracket fixed on the concrete foundation near the bottom of the vessel. The mixer is lined with refractory

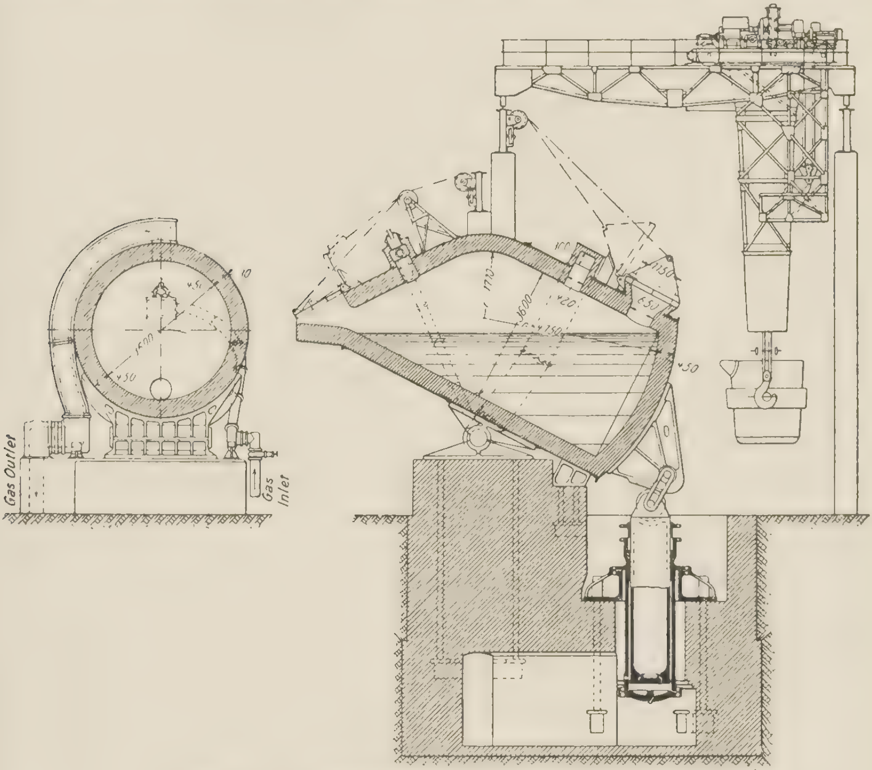


FIG. 179.—Converter Type of Mixer (oil or gas fired).

materials, basic or acid, according to the kind of iron being produced in the blast furnaces.

One arrangement of overhead crane for carrying the ladle of metal to the mixer is also shown. The contents from the mixer are tipped into a ladle suspended from a crane similar to the one shown but on the other side, or into a ladle mounted on a loco. truck, according to the arrangement of the works.

Open-hearth Type of Mixers.—Another design of mixer used for large quantities of metal is that shown in Fig. 180, which illustrates a 900-ton mixer mounted upon four roller frames bolted to foundations, the mixer being controlled by two hydraulic cylinders and rams at each end. There is a port hole at each end of the mixer which connects with the flues from the regenerators, through which heat is supplied to the mixer. The regenerators and flues are not shown in the Fig. The metal from the blast furnace is poured into the mixer at one side and emptied at the other. The body of the mixer is made of rolled plates rivetted together, and has four substantial roller-path castings bolted in segments right round the body of the mixer. The inside is lined with refractory material.

Details of Roller Path.—The details of construction of roller paths and how the castings of which they are formed are fixed to the body of the mixer, are

illustrated in Fig. 181. The arrangement for rotating the mixer is different from that previously described. In this design a toothed segment is bolted to the underside of the mixer, and a pinion which engages with it derives its

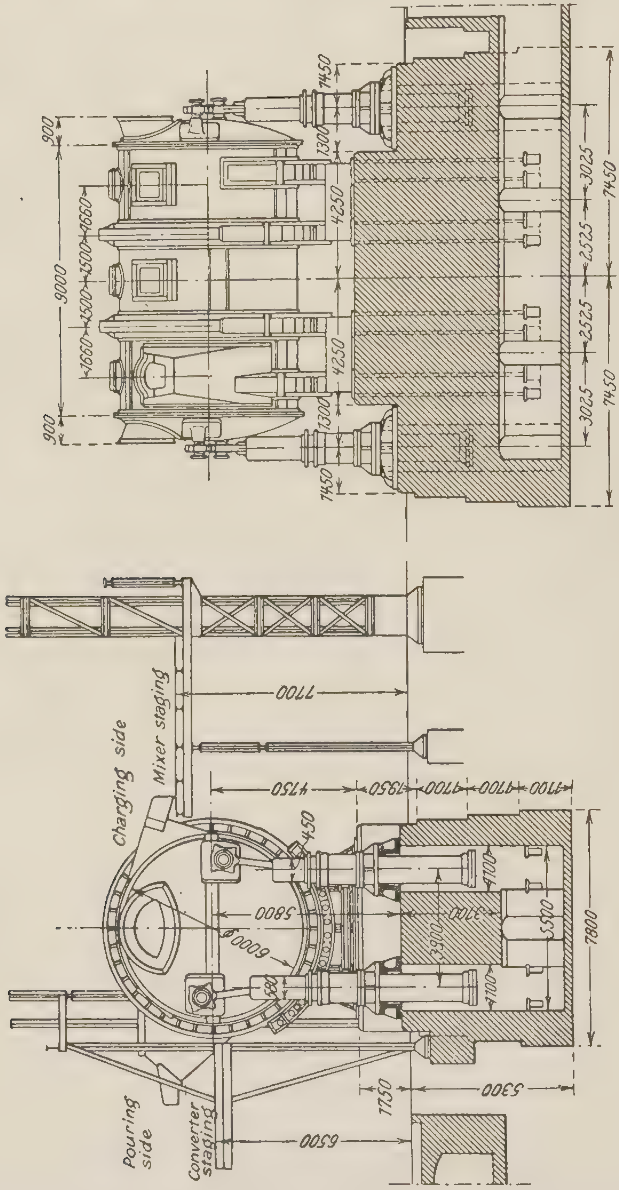


FIG. 180.—Open-hearth Type of Mixer (900 tons capacity).

motion through suitable gearing from an electric motor. The end plates of the mixer are bolted to the body in a very substantial manner, as shown by the illustration.

Mixer with Regenerators.—Fig. 182 represents a sectional elevation of a

mixer mounted between the gas and air ports of two sets of regenerators. The mixer is arranged like an ordinary tilting open-hearth furnace, differing only in the construction and in the size of the rotating part, or mixer proper. The reversal of gases is made periodically as in the ordinary regenerative furnaces. The metal is received into and is poured from the mixer on the same side but at different ends. Fig. 183 shows a photo of the mixer and staging complete.

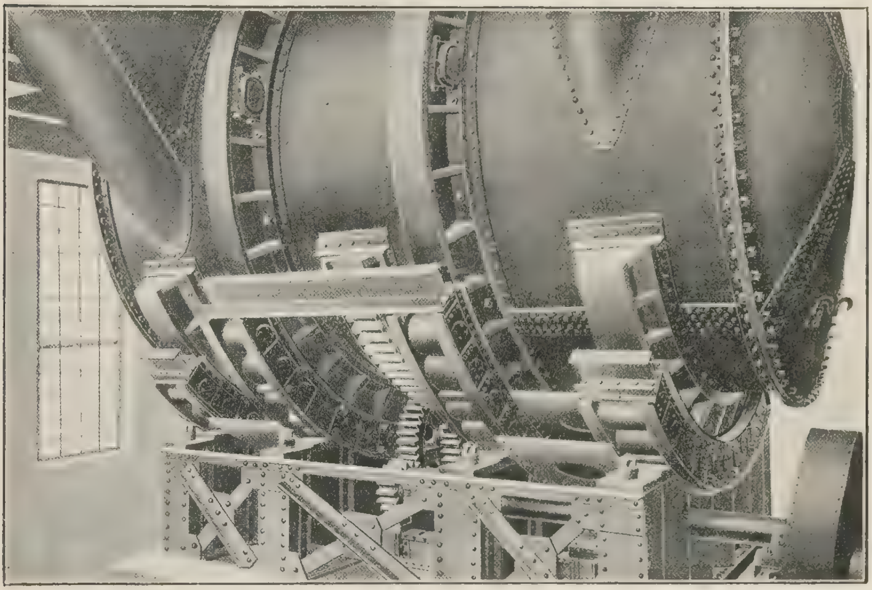


FIG. 181.—Details of Roller Paths of Mixer.

Capacity of Mixers.—Mixers are made with capacities varying from 150 tons to over 1000 tons. Some difference of opinion exists as to the most suitable size of mixers for use in steelworks practice. When mixers are used as refiners of metal as well as collectors and distributors, the wear on the linings is severe. Dr. Petersen, in reviewing the present position of the basic open-hearth process, suggests that the size of mixers used as refiners should not exceed 250 to 300 tons capacity, in view of the great corrosion of the lining by the action of the oxides and slag, as well as the difficulty attending the emptying of such large vessels. It is a fact, however, that small mixers of 200 tons capacity are being replaced by mixers of larger capacities. The limitations of small mixers retard the progress in steelworks where the demands upon the mixer or mixers are great. The decision as to the best size must depend upon the particular conditions of steel manufacture in each works.

The Mixer as a Refiner. Unheated Mixers.—The mixer is of great value to the Bessemer and open-hearth processes as a refiner. When used only as a collector and desulphuriser, large percentages of the various impurities (excepting carbon) are removed. One remarkable feature, brought out by Prof. O. Simmerbach of Breslau, in a most instructive paper given by him on pig iron mixers,[1] was that desulphurisation was effected equally well in heated or unheated mixers. The following changes were recorded in the composition of

[1] "Stahl und Eisen," March 9th, 1911.

good basic pig iron containing 1·1 to 1·3 per cent. of manganese, from the time of leaving the blast furnace at some distance from the mixer, until converted into steel.

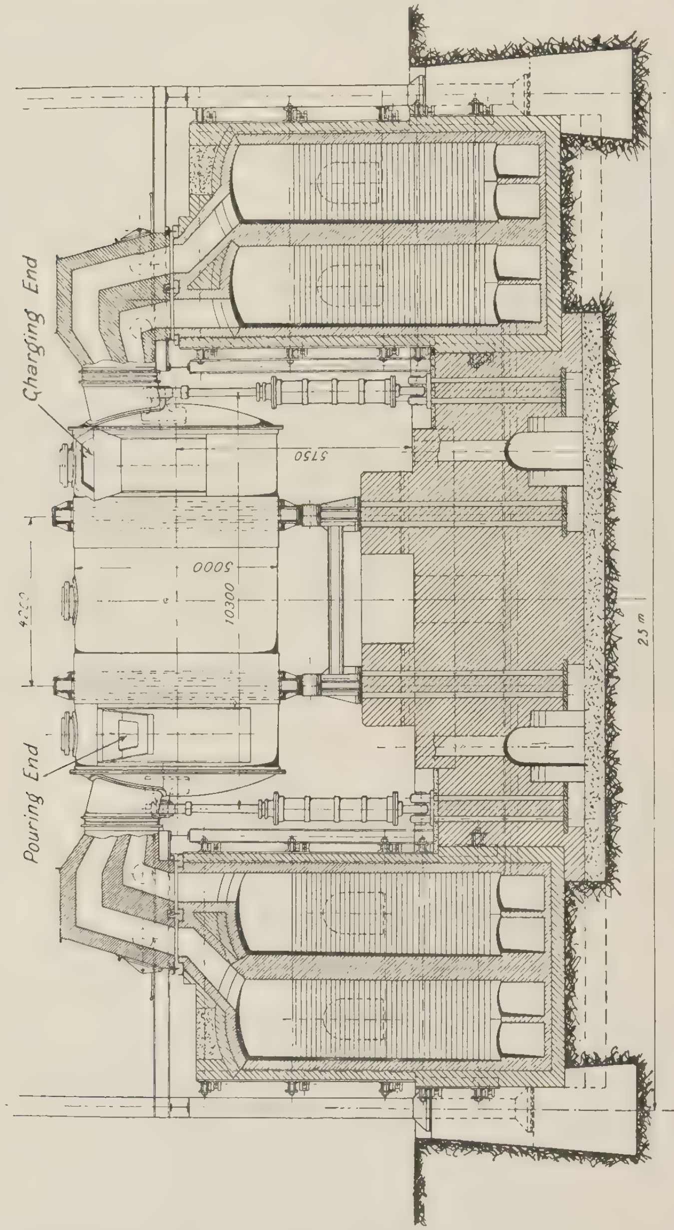


FIG. 182.—Gas-fired Open-hearth Type of Mixer with Regenerators.

1.	Average sulphur at blast furnace	0·254 %
2.	Average sulphur entering the mixer	0·100 %
3.	Average sulphur entering the converter . . .	0·084 %
4.	Average sulphur of finished steel	0·052 %

The notable reduction in sulphur is that which took place in the ladle while being conveyed from the blast furnace to the mixer, and is equal to 76·24 per cent. of the total reduction of sulphur, while 7·29 per cent. took place in the mixer, and the remainder in the basic converter. It was found from other tests that when the iron contained a lower percentage of manganese less sulphur was removed during the transfer of the metal from the blast furnace to the mixer. The mixer had a capacity of 750 tons, and the average analysis of the metal over four days was:—

Si, 0·49; Mn, 1·06; P, 1·98; S, 0·085 per cent.

Heated Mixers.—The degree of refinement of metal in heated mixers is under direct control, just as much as the metal in the open-hearth furnace.

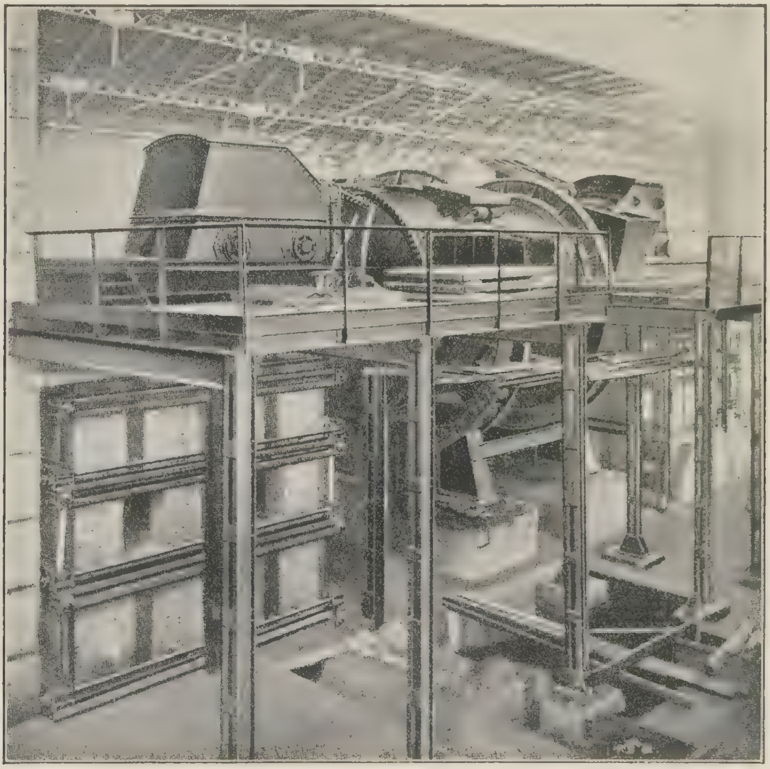


FIG. 183.—Mixer and Staging.

Mixers are heated with producer gas and air, oil and air, or blast furnace or coke oven gases. The temperature of the metal can, therefore, be regulated to meet the most favourable conditions for the elimination of the impurities it is particularly desired to remove.

The following results were obtained from a 200-ton mixer heated with producer gas and air, the air only being preheated. The temperature of the pig iron on entering and leaving the mixer was 1245° C. and 1350° C. respectively. To the iron, which contained Si 1·4 per cent., Mn 1·00 per cent., S 0·14 to 0·17 per cent., P 0·80 per cent., as it entered the mixer were added $\frac{1}{2}$ per cent. of ore and $1\frac{1}{2}$ per cent. of lime. It is recorded that during a period of five weeks

the average removal of Si was 30·29 per cent., and of sulphur 50·54 per cent. The ore contained 3 per cent. of Mn favouring, along with the high temperature of the mixer, the desulphurisation of the iron.

Silicon, however, can be reduced much more than 30 per cent. Mr. P. S. J. Cooper states[1] that at the North-Eastern Steel Works, Middlesbrough, where they have two 400-ton gas-fired mixers in operation, the silicon was reduced from 1·8 per cent. to as low as 0·5 per cent., and frequently lower.

Other instances of charges and compositions could be given showing the value of the mixer as a refining furnace.

Operation of Mixers.—When a mixer is newly installed, the usual care bestowed in drying an open-hearth furnace is as necessary for the lining of the mixer, flues, and regenerators before filling the mixer with metal. Mixers with no heating attachments are dried with coal and coke fires assisted by an auxiliary blast of air from a flexible pipe connection, or they may be dried by other suitable fuels, such as producer gas, oil jets, etc., if these can be carried conveniently to the mixer. Where two mixers serve a steel plant, the metal from the blast furnace is charged into one, while metal is being drawn from the other for the steel furnaces. This alternate use of the mixers allows more time for chemical reactions than when the operations are conducted in one mixer only.

Weighing the Metal taken to and from the Mixer.—Different methods are employed for weighing the metal going into and taken from the mixers. Weighbridges are usually placed in some convenient position, either adjoining the entrance to or inside the mixer building, to weigh the metal as it comes from the blast furnace. The ladle, when weighed, is lifted from the truck by an overhead crane and carried to the mixer, or the truck is pushed in front of the inlet to the mixer and the ladle tipped while on the truck, and the contents poured in.

For weighing the metal taken from the mixer an empty ladle on a truck is placed on a weighbridge under the mixer platform in a position to receive the metal. The operator controlling the movement of the mixer has in front of him the weighbridge arm, which shows what weight of metal goes into the ladle. He can, therefore, control the weighing and pouring at the same time. When weighed the ladle of metal can be drawn away by a locomotive to the furnace to be charged, or lifted from the truck by an overhead crane and taken to the furnace or converter, if the plant is arranged so that the overhead crane controls both mixers and furnaces.

[1] "Journal Iron and Steel Institute," 1908, III, p. 195.

CHAPTER XXXI

GAS PRODUCERS

THE economical supply of good gas in sufficient quantities is one of the most important items in the working of an open-hearth or other furnace for steel manufacture where gas fuel is used. Increases in the price of coal, advances in wages, and keener competition, call for the use of cheap grades of coal and demand that the maximum amount of good gas shall be obtained from them. When coal was cheaper, competition less keen, and profits more easily assured, good quality coal was deemed essential for the production of gas, but of late years the employment of cheaper qualities of coal has necessitated modifications in the types of producers, many makes of which are now in use, each designed with the object of generating good gas from common grades of coal as economically as possible. Though many of the producers differ from one another the methods of working are in most cases the same.

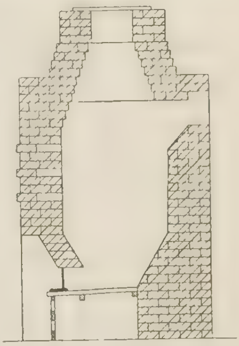


FIG. 184.—The Bischof Producer.

Historical.—The first internally-fired gas producer is supposed to have been invented in 1839 by Bischof, an Austrian. It was used in connection with a metallurgical furnace, the passage of air through the incandescent fuel bed being obtained from the chimney draught. The gas generated was drawn off through the outlet to the furnace, whilst fresh fuel was fed in through the opening at the top. No steam was used with the air. Fig. 184 gives a section of the producer.

In 1840, Ebelmann introduced a producer, see Fig. 185, which had for its object the decomposition of the tarry hydrocarbons, by constraining the volatile gases to pass through the bed of incandescent fuel before leaving the producer. The producer was constructed with a charging bell through which the fuel gradually descended to the combustion zone. This feature is still retained in some modern producers, and while its original object cannot be said to be very successful, the bell acts as a storage chamber for heating the coal before it descends to the bed of incandescent fuel.

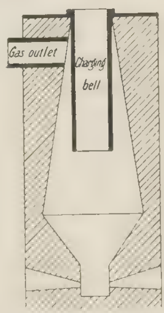


FIG. 185.—The Ebelmann Producer.

With the introduction of the gas-fired open-hearth and crucible furnaces by Sir William Siemens and his brother Frederick, it became necessary to provide suitable means for producing gas on a commercial scale for use in these furnaces. They therefore designed a producer[1] in 1861 to meet their requirements. It consisted of a brick chamber with an inner lining of firebricks, containing an inclined grate, the upper portion of which was composed of iron plates lined with firebricks, whilst the

[1] Siemens, "Collected Works," vol. i. p. 219.

lower portion consisted of flat steps arranged horizontally. At the foot of the grate was a covered water trough supplied from a cistern. The fuel was introduced at the top through holes at intervals, and the poking of the fuel bed accomplished by means of a bar inserted through holes.

When working the producer, gas was generated by a current of air passing through the grate and by steam given off from the water trough, through holes at the side. To maintain a pressure within the gas flue, the producer was either placed at a lower level than the furnace, or the arrangement shown in Fig. 186 was adopted. The horizontal flue marked "A" being exposed to the atmosphere, caused a drop in temperature of the gas, resulting in an increase in its density, which, acting on the descending column, forced the gas forward to the furnace and maintained an internal pressure in the flues.

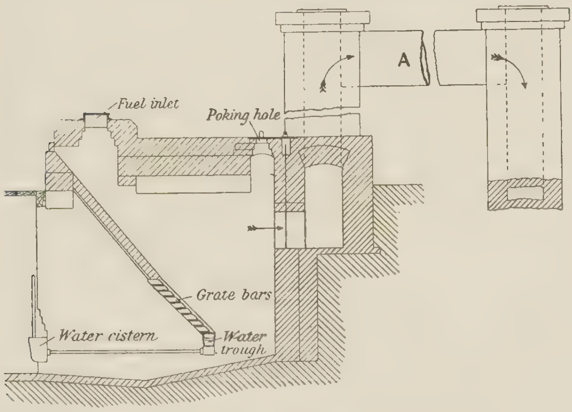


FIG. 186.—Siemens' Original Producer.

Since Siemens introduced their producer, many improvements have taken place and many patents have been granted in connection with these improvements. The main idea, however, has been the same throughout, namely, the production of a combustible gas from a bed of incandescent fuel by the passage of air, or air and steam through the mass.

The essential features of economical and efficient working may be summed up as follows:—

(1) A bed of incandescent fuel of sufficient depth to ensure an almost complete reduction of CO_2 to CO, and at the same time the decomposition of the steam.

(2) Facilities for ready removal of ashes and clinker.

(3) Uniform and continuous production of good quality gas.

(4) Even distribution of fuel.

(5) Simplicity of design, involving minimum labour and repairs.

Solid Bottom and Firebar Bottom Producers.—These producers are not often used because of the difficulty in clearing the ashes while the producers are at work.

A few of the producers retain the solid bottom and firebar bottom, and it is worthy of note that a recently developed producer, namely the S.F.H. type described on page 346, is made with a solid bottom. From the description of this producer, however, it will be seen that its method of working is somewhat different from that of the usual types of producers, hence the somewhat remarkable design.

Water-Bottom Producers.—Most modern producers are of this type, differing somewhat in their details of the water-filled ash pans and the method adopted for the removal of the ashes. In some cases the ashes are raked out and loaded into trucks or carts, in others mechanically discharged.

The method of introducing the steam and air into the fuel bed varies in different designs, depending upon the arrangement of the grate or tuyere. In

some producers, the air and steam pass through a tuyere at the bottom and in the centre of the producer, the tuyere being covered with a cap to prevent the fuel and ashes from choking the pipe. In other producers, grates of various designs are fitted, which may be either fixed or have a rotary movement with the object of breaking up the fuel and clinker, the air and steam passing through holes in the grate to the fuel bed.

Distribution of Fuel.—In many producers the fuel is fed through a feeding hopper at intervals, poked down, and levelled off as well as possible. This method of feeding coal is now being recognised as unsatisfactory, because large quantities of cold coal introduced intermittently do not tend to produce gas of uniform quality. These bell and hopper hand-fed producers are therefore now giving way to mechanically fed producers in which the coal is continuously distributed over the fuel bed, thus maintaining an uniform range of temperature and producing an uniform quality of gas.

The Bildt Mechanical Feed.—The first type of mechanical feed was introduced in America, and is known as the Bildt feed. It consists of a coal hopper, just below the outlet of which is arranged a disc rotated by means of gearing. The disc can be raised or lowered to suit the size of the coal used, which is distributed evenly over the fuel bed by reason of the shape of the disc and its speed of rotation.

Coal Handling Plant.—The introduction of mechanically fed producers has consequently led to improvements in coal handling in the producer house. Originally the coal was shot on to the staging in heaps and then shovelled by hand into the hoppers as required. Coal handling plants on an elaborate scale are now fitted for working in conjunction with producers of the mechanically fed type. The arrangements depend to some extent upon surrounding conditions, but the general idea is the same, *i.e.* the provision of a coal storage above the producers, from which the fuel can be fed into the hoppers of the producers to ensure a constant supply.

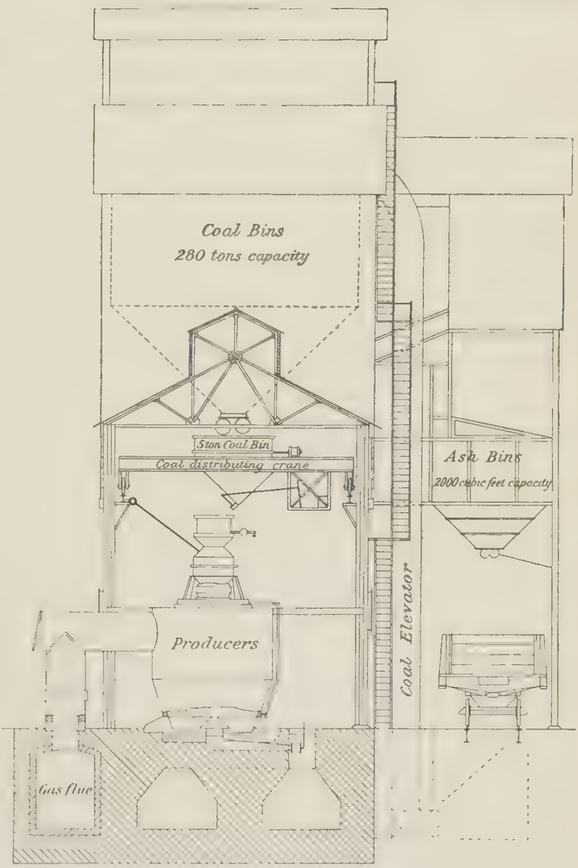


FIG. 187.—Coal and Ash Handling Plant (Morgan's).

Fig. 187 shows a typical arrangement of coal-handling plant installed at the Lackawanna Steel Co.'s works, Buffalo, U.S.A. There the coal is brought in

trucks to the railway siding which runs alongside the gas producer house, then dumped into an elevator pit and carried up to two coal bins, each of 280 tons capacity, situated above the top of the house. From these bins the coal is collected in a bin of 5 tons capacity fixed to an overhead travelling crane, and this supplies the hoppers of the sixteen 10-feet-diameter Morgan producers below.

Mechanical Poking.—As an alternative to mechanical feeding, some producers are fitted with mechanical poking arrangements, whereby the coal, fed by a bell and hopper, is distributed evenly by means of a poker worked continuously, and which also has the advantage of thoroughly stirring up the fuel. Hand poking is thereby avoided, and the cost of labour in working the producers diminished.

Bye-Product Recovery.—Many investigations have been made of recent years concerning the recovery of bye-products from gas-producing plants. In districts where producer gas is made on a large scale for sale to factories, and in large generating stations, it has been found economical to instal plant for the recovery of ammonia and tar, but in steelworks where gas producers are used in conjunction with the open-hearth plant, somewhat different circumstances prevail, and a difference of opinion exists as to the advisability or otherwise of recovering these bye-products from the gas before it is supplied to the open-hearth furnaces.

For valuable information on the recovery of ammonia from gas producers, reference should be made to papers read by Mr. Humphrey [1] and Messrs. Bone and Wheeler.[2] The Mond producer, introduced by Dr. Ludwig Mond, F.R.S., has been especially developed for ammonia recovery. The essential condition for ammonia recovery lies in the injection of a large quantity of superheated steam with the air into the producer. The latter, therefore, works at a lower temperature than in ordinary non-recovery producers, with the result that the ammonia produced is not decomposed, but passes out with the gas and a large proportion of undecomposed steam into the recovery apparatus, where the steam is condensed, the ammonia absorbed, and the gas cooled and passed on to the furnace.

The ammonia, which is absorbed by sulphuric acid, forms ammoniacal liquor, a solution of ammonium sulphate. This is then evaporated until the sulphate crystallises out, and after drying, is ready for sale. Sulphate of ammonia is being increasingly used as a fertiliser.

While the sulphate realises from £10 to £14 per ton, there is also the charge for depreciation and interest on the plant. Labour, repairs, cost of sulphuric acid, coal for distillation, etc., are other factors. The economy or otherwise of ammonia recovery depends primarily upon the amount of coal gasified. The suitability or otherwise of the gas produced for use in open-hearth furnaces also requires consideration. In a Mond plant worked with ammonia recovery, the gas contains about 11 per cent. of CO, while the hydrogen and carbon dioxide present approximate 27·5 and 16·5 per cent. respectively.

Some steel-makers are of opinion that gas for open-hearth furnaces should be rich in carbon monoxide and tarry vapours, as these give a luminosity to the flame, and, being slower of combustion, develop a more uniform heat in the furnace. According to Mr. Sehmer,[3] open-hearth steelworks in Germany "would not accept a producer generating normally more than 10 per cent. of hydrogen, and as a maximum 14 per cent.," which bears out the opinion that producer gas high in hydrogen and consequently low in carbon monoxide is unsuitable for open-hearth practice.

[1] "Proceedings Institution of Civil Engineers," vol. cxxix, pp. 190–217.
[2] "Journal Iron and Steel Institute," 1907, I, pp. 126–180.
[3] *Ibid.*, p. 175.

Fuel used in Gas Producers.—The capacity of a producer and the analysis of the gas produced depend to a great extent upon the fuel used, and it is insufficient to state that a producer has a capacity of so many tons per day or will give a gas of a certain analysis, without at the same time giving particulars of the fuel used. As instances of the dependency of the output and analysis of gas on the fuel used, Table LXXXI gives the output of gas from the same make of gas producer when used on different grades of fuel, and Table LXXXII, p. 330, is a record of the working of thirteen gas producers, all of the Kerpely type, showing the varying analyses obtained.

TABLE LXXXI

SIZES AND CAPACITIES OF HILGER GAS PRODUCERS

Fuels.	Capacity of producer in tons per 24 hours.			
	6′ 7″ diam.	7′ 3″ diam.	8′ 6″ diam.	9′ 10″ diam.
Bohemian lignite	16–18	20–22	26–29	33–36
Rhenish lignite briquettes	16–18	20–22	26–29	33–36
Washed nut coal	10–12	12–14	16–19	21–24
Rough coal with 20% dust	9–11	11–13	15–18	19–22
Pea coal with 50% dust	7·5–8·5	9–11	12–14	16–18
Waste coal	6–6·5	7–8	9–11	12–14

The fuel mostly used in producers worked in conjunction with open-hearth furnaces is lignite (brown coal), bituminous or anthracite coals, or coal dust briquettes. Coals with even large percentages of ash can be worked, as a rule, without much difficulty in water bottom producers, but care should be taken that in these cases the sulphur content is low. It is the presence of sulphur which, melting and combining with the ash to form clinker, causes most trouble in gas producer working, and thereby renders an otherwise cheap coal relatively of less value than a better quality coal. Further, a certain amount of the sulphur in coal is carried over with the gas to the furnace, which may be kept as low as possible by using low sulphurous coal.

Probably the best fuel for the purpose is good screened coal crushed to about $1\frac{1}{2}$ to 4-inch cubes. Slack coal, although lower in cost, is usually less economical in the end, as it yields a poorer quality of gas, chokes the producer, and increases the cost of labour.

TYPES OF MODERN PRODUCERS

In the following pages descriptions and illustrations are given of some of the best known types of gas producers employed in conjunction with open-hearth steel plants, arranged alphabetically in three groups—British, American, and Continental. The particulars of outputs, etc., given do not apply to the use of the same fuels and the prevalence of similar working conditions in each case, but are the results of actual working in different countries and under varying circumstances. No attempt is therefore made to compare the many types of producers described, but typical costs are given on page 347, based on the information set forth in the following descriptions, which are fairly representative of the results obtained from several of the leading types of modern producers.

BRITISH GAS PRODUCERS

The Dawson Producer.—This producer, a section of which is given in Fig. 188, is of the water bottom type, and consists of a cylindrical shell lined with

TABLE LXXXII

AVERAGE RESULTS OBTAINED FROM KERPELY GAS PRODUCERS

No.	Origin of fuel.			Characteristics of fuel.	Size of fuel.	Average percentage analyses of fuel.					Net calorific power. B.Th.U. per lb.	Average percentage analyses of gas.					Net calorific power of gas without tar. B.Th.U. per cu. ft.
	Country.	District.	Locality.			Fixed carbon.	Volatile matter.	Ashes.	Moisture.	Sulphur.		CO_2	CO	H	Hydro-carbons.	Total combus-tibles.	
1	Gt. Britain	Yorkshire	Pearn Valley, Sheepbridge.	Coking and swelling	Nuts down to dust	54·8	29·5	6·2	7·8	1·3	11,500	4·0	29·0	10·0	3·7	42·7	162
2	,,	Newcastle	—	Coking	Nuts with 30% dust	52·2	35·6	6·5	5·8	0·9	12,050	2·2	28·6	9·0	2·5	40·1	148
3	Belgium	Mons.	Flenu	Coking. Tendency to clinker	Nuts, peas, and fine coal	—	33·3	5·0	—	—	11,900	3·5	27·5	11·6	3·4	42·5	158
4	France	St. Etienne	Decize	Very strong coking	Peas	60·0	19·6	13·1	7·3	1·2	13,150	4·5	25·4	8·6	3·6	37·6	146
5	Austria	Styria	Fohnsdorf	Peacock coal	Rough coal	48·0	27·0	17·0	10·0	2·2	9,000	2·8	30·5	14·0	2·1	46·6	162
6	,,	Silesia	Dombrau	Coking	,,	57·2	28·1	11·5	3·2	—	11,900	4·0	25·0	13·0	1·5	39·5	135
7	Hungary	Királd	Bánszállás	Lignite	Rough coal with 60% dust	18·5	36·9	16·0	24·0	0·8	5,750	5·0	27·0	13·6	1·8	42·4	146
8	Bosnia	—	Banjaluka	,,	Nuts and peas	11·8	55·3	20·6	15·0	3·8	7,550	5·5	26·5	12·0	1·5	40·0	136
9	Germany	Rhenania	Brühl	Briquettes	2″ to 3″	47·3	34·8	4·6	13·3	—	8,800	3·4	31·5	11·0	2·5	45·0	162
10	,,	Westphalia	Werne	Coking and swelling	Rough coal with 40% dust	57·0	31·0	8·0	4·0	—	12,050	2·7	27·5	6·0	3·6	37·1	147
11	,,	Silesia	Friedensgr	Coking	Peas	59·4	28·7	7·8	4·1	—	12,500	3·2	26·8	9·3	6·0	42·1	172
12	Russia	Polonia	Mine Park	Non-coking	Washed nuts, ½″	48·0	32·0	8·5	11·5	—	10,100	1·4	31·5	12·4	2·2	46·1	162
13	,,	South	Alexandrow	Very strong coking	Rough coal	49·5	32·7	16·2	1·5	3·1	11,500	2·2	27·8	10·0	3·8	41·6	159

firebricks, resting on columns in the water trough. This water trough forms a

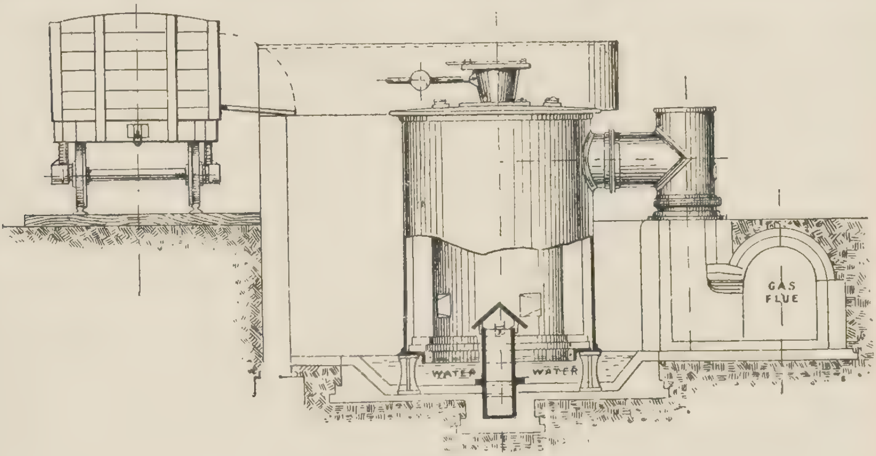


FIG. 188.—The Dawson Producer.

receptacle for the ashes and clinker as they descend, and at the same time acts as a water seal for preventing the escape of gas while the producer is at work. Coal is fed in by the bell and hopper arrangement at the top, and the air and steam are injected through a central tuyere provided with a conical cap for preventing the fuel from choking the blast pipe. The gas is drawn off at the gas outlet at the top of the producer, from whence it passes through the flue to the furnace.

The Duff Producer.—The Duff producer, illustrated in Fig. 189, has been designed for burning low grade bituminous coals, and is of the water-bottom type, fitted with a large grate to ensure an even distribution of air and steam over the area of the fuel bed. Doors are fitted in the sides to obtain access to the interior of the producer for repairs or inspection. Coal is fed in by the usual bell and hopper. The producer is made in five sizes, having gasifying capacities of 1, 2, 5, 10 and 15 cwts. of coal per hour respectively.

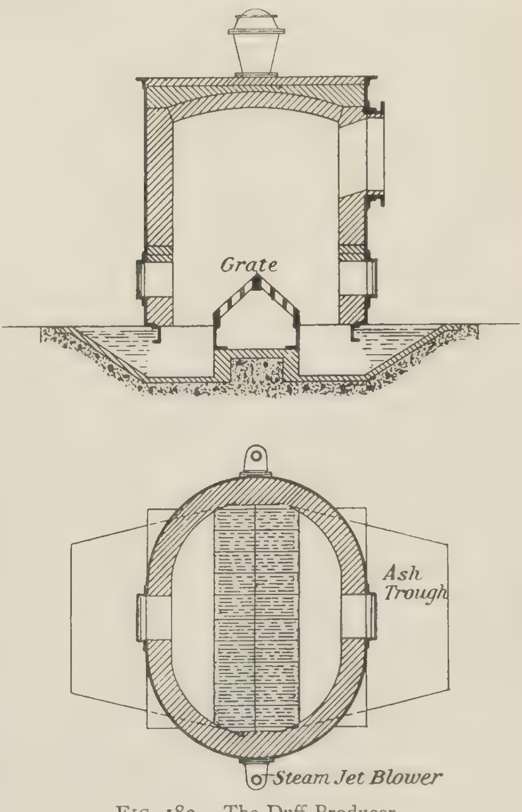
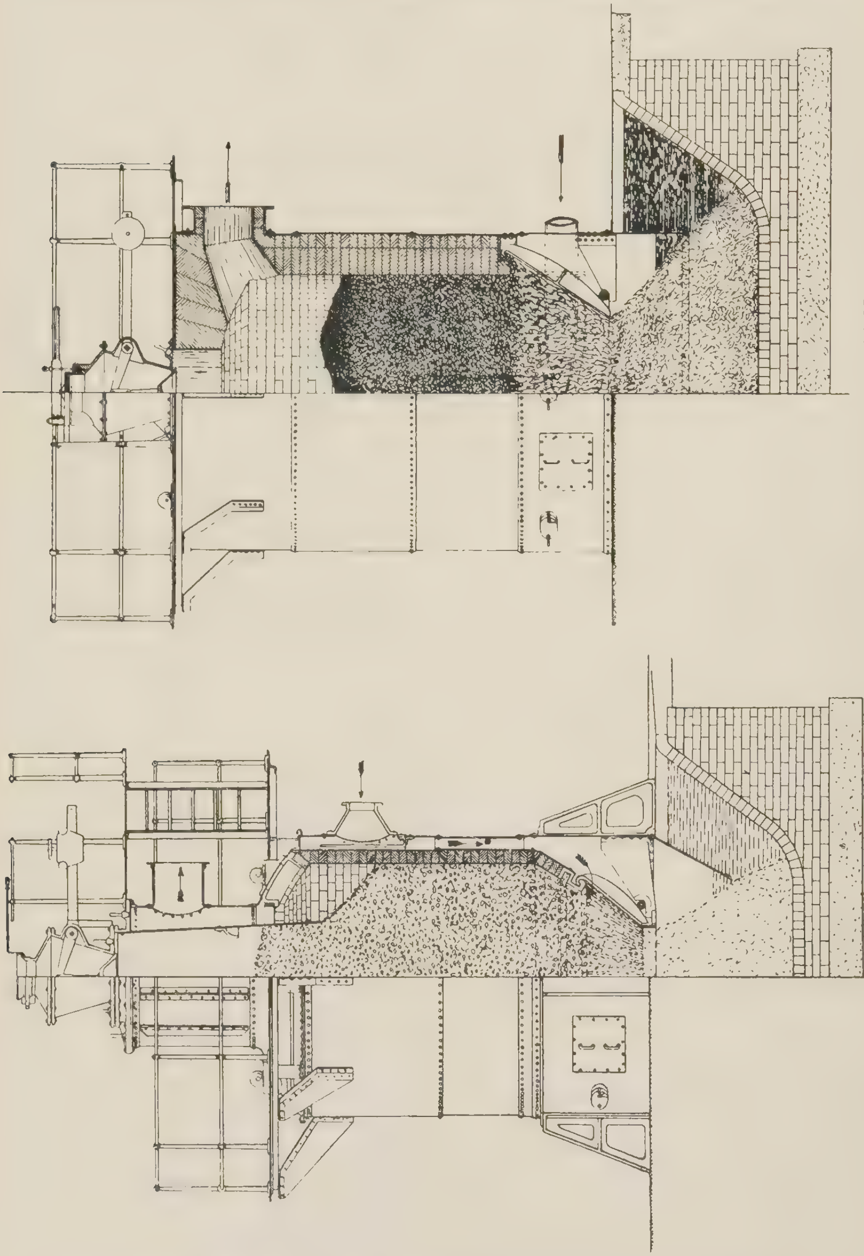


FIG. 189.—The Duff Producer.

The first four sizes are constructed with a circular shell; the latter with an oval shell, in which air and steam are blown under the grate from two sides.



(*b*) Non-recovery type.

(*a*) For bye-product recovery.

FIG. 190.—The Mond Producer.

The Mond Producer.—The Mond producer, introduced by the late Dr. Ludwig Mond, F.R.S., is constructed either for use with bye-product recovery or for non-recovery. The two types of producers are shown partly in section in

the accompanying Fig. 190. The producer, when constructed for the recovery of bye-products (Fig. 190 *a*), consists of an inner shell lined with firebrick, and an outer jacket fitted round the inner shell leaving an annular space of 2 or 3 inches, down which the blast is made to pass from the upper blast inlet to the grate. The outer jacket is extended into a water seal formed in the foundation. A cylindrical bell is fitted into the top of the producer itself, into which the fuel is fed from the charging hopper, so that the fuel is heated by the outgoing gases as they leave on their way to the gas outlet; the object being to convert the light hydrocarbons given off from the distillation of the coal into fixed gases, by directing them downwards through the hot fuel bed before they can ascend to the gas outlet. A large amount of steam is used with the blast, amounting to as much as 2½ lbs. of steam per lb. of coal gasified. After leaving the producer, the hot gas passes first through a tubular recuperator in which it gives up some of its sensible heat to the incoming air and steam. The gas then enters a mechanical washer consisting of a rectangular chamber in which the gas is brought into contact with water sprayed by revolving dashers. The temperature of the gas is considerably reduced, and dust and tar partly extracted. From this washer the gas is led to an apparatus in which the ammonia in the gas is fixed by weak sulphuric acid, forming a solution of ammonium sulphate. This solution, known as ammoniacal liquor, is periodically

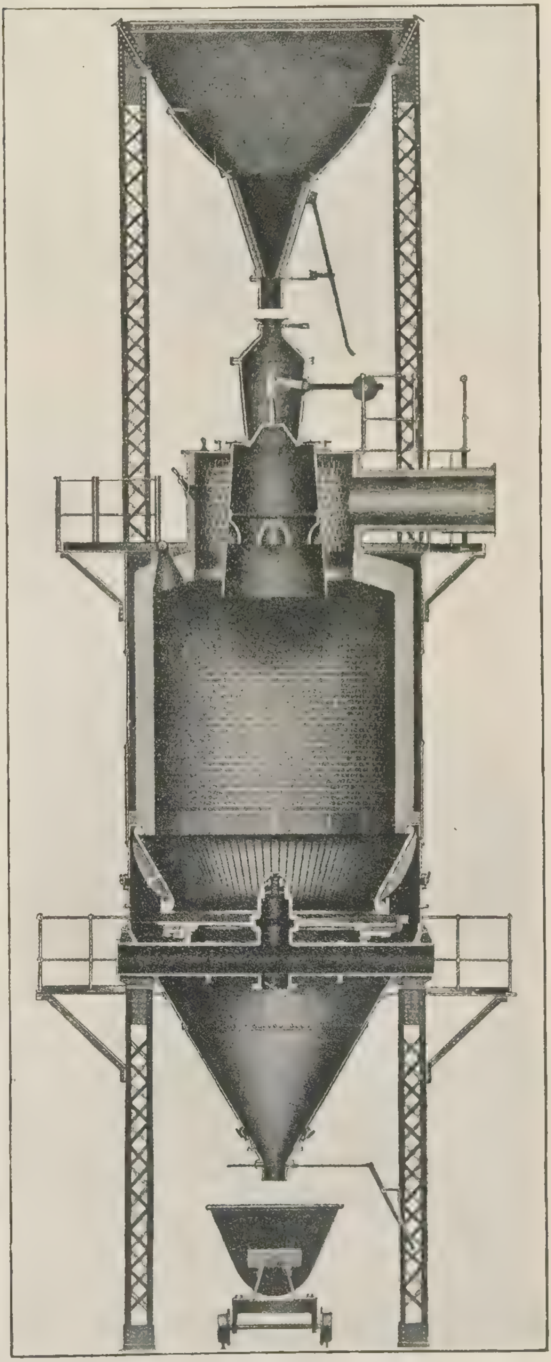


FIG. 191.—The Mond-Trump Producer.

withdrawn and either sold for re-distillation or converted on the site by evaporation into sulphate of ammonia. The gas, freed from ammonia, is then ready for use.

In the non-recovery type of producer shown in Fig. 190 *b*, the construction is somewhat different in that the annular space and jacket are dispensed with. The cylindrical bell is also omitted, and the producer resembles the well-known water-seal bottom types. The gas in this case passes "hot" from the producer to the furnace.

When worked on coals giving a high percentage of ash, these producers are sometimes fitted with a mechanical dry ash discharge, and are then known as Mond-Trump gas producers. Fig. 191 represents the producer as supported upon a steel framework, with a conical ash collector fixed for the convenient discharge of ash into trucks below.

Typical analyses of gas produced from Mond plants used with and without ammonia recovery are given :—

MOND GAS FROM BITUMINOUS FUEL

	Without Ammonia recovery.	With Ammonia recovery.
CO	23·0 %	11·0 %
H	17·0 %	27·5 %
Hydrocarbons	3·0 %	3·0 %
CO_2	5·0 %	16·5 %
N + moisture	52·0 %	42·0 %

The Siemens Producer.—Many modifications and improvements have been

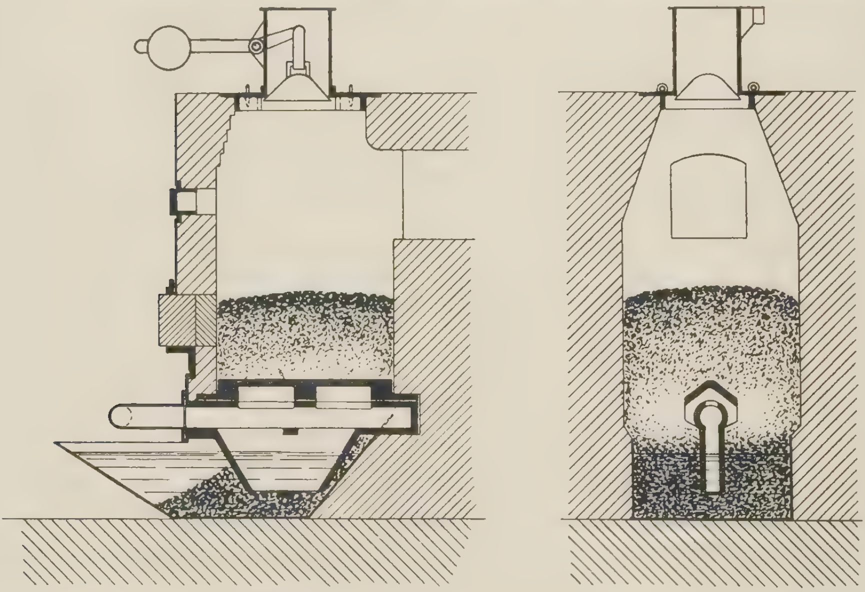


FIG. 192.—The Siemens Producer.

made in Siemens producers since first introduced in 1861. One of the modern types now used in connection with open-hearth furnaces in which the producer

is suitable for being built into the ground, is shown in Fig. 192. This producer is water sealed, and can be continuously operated. The familiar hopper is fitted for the charging of the fuel. Since the charging is done from the ground-level, this type of producer is particularly suitable where coal is delivered to the plant at the same level, since the coal can be distributed around the producer and easily fed into the hoppers by hand.

With the cylindrical types of producers which usually stand on the ground-level, the charging hopper is several feet above the ground and consequently a charging platform must be erected for working upon. If the coal is not delivered to the producer plant at a high level it must be raised to the platform by means of elevators or lifts.

The Thwaite Producer.—Producers of different types have been introduced by Mr. B. H. Thwaite, one type being illustrated in Fig. 193. The producer shell, which is cylindrical and lined with firebrick, is fitted with an airbelt or jacket through which the air necessary for the combustion of the fuel is drawn, and heated in its passage to the fuel bed. The producer is fitted with grate bars, a water bottom, and the usual feeding hopper, poking holes, etc., found in most types of modern producers.

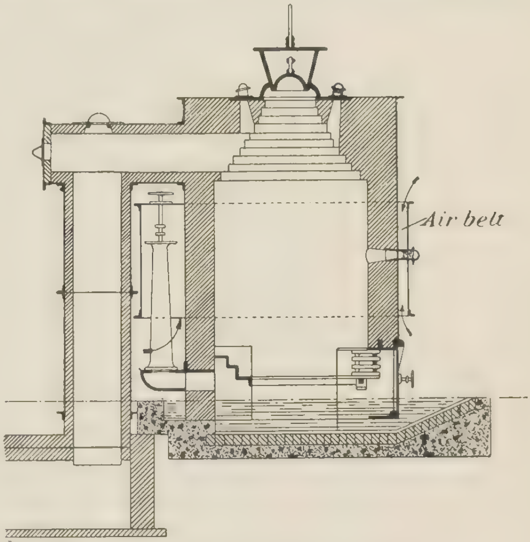


FIG. 193.—The Thwaite Producer.

With a view to breaking up the volatile matter in coal and converting it into fixed gases, Thwaite introduced a double producer in which the gas generated is passed alternately through the hot fuel in each producer before it is drawn off. Another design of Thwaite producer has for its object the enrichment of the producer gas by means of oil gas.

The Wilson Producer.—In its original form this is a solid bottom producer, cylindrical in plan and provided with cleaning doors through which the ashes and clinker are removed periodically. An improved type of producer has therefore been constructed for continuous operation, and is shown in Fig. 194. It consists, as before, of a cylindrical shell lined with firebrick, but at the bottom an Archimedean screw is fitted which, revolving slowly in a water ash pan, ejects the ashes continuously. The producer is also provided with a revolving tuyere, which has the effect of agitating the bed of fuel besides distributing the supply of air and steam over the area of the fuel bed.

A further modification in the form of a mechanical charging device has been fitted, and consists of a rotating hollow drum which becomes filled with coal from a coal hopper above, and on rotation discharges its contents over the fuel bed.

In cases where the separation of dust from the producer gas is considered desirable, this producer may be used in conjunction with a dust trap built within the casing of the producer, and consisting of a cylindrical chamber lined

with firebrick arranged alongside the gas producer proper and enclosed in the same casing. The gases from the producer chamber which issue at the top, pass down a flue to the bottom of the water luted dust trap which is filled with clinkers, cinders, or slag, and passing through this scrubbing material the gases deposit the dust, while at the same time, owing to the high temperature maintained, the tarry matter is not condensed.

A Wilson automatic cleaning gas producer as illustrated in Fig. 194, 10 feet

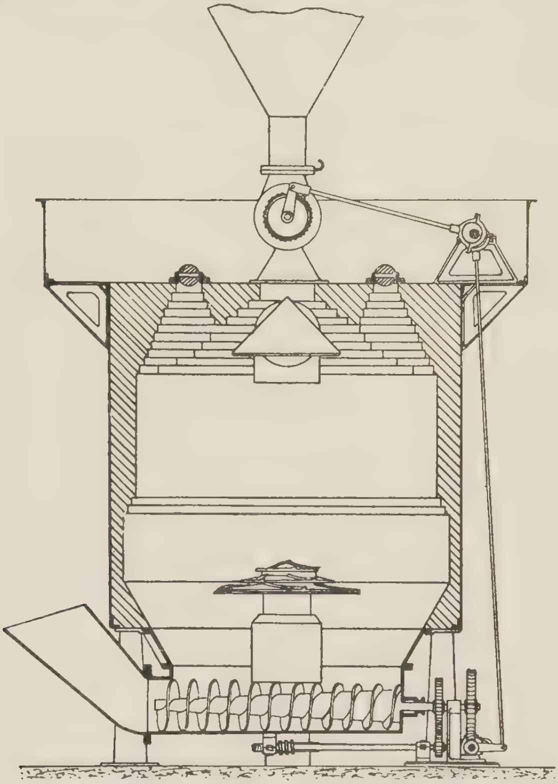


FIG. 194.—The Wilson Producer with Automatic Feed and Ash Ejector.

internal diameter, will gasify about 1 ton of low quality slack coal per hour. The cost of a Wilson producer plant suitable for working a 10-ton open-hearth furnace is about £300 to £400.

American Gas Producers

The Forter-Trump Producer.—This producer has been designed with means for automatically feeding the coal and removing the ash. The producer itself is of the cylindrical type with a conical-shaped bottom which forms a water-seal in the ash pan below. Air and steam are blown through a circumferential grate extending all round the body of the producer, and also through a central tuyere. The feeding device consists of a knife and water-cooled table which rotate at different speeds, resulting in the distribution of coal evenly over the fuel bed. The ashes are cut away in sections by a revolving knife and

thrown into a groove round the table, from which they are discharged into the water-seal ash pans by two scoops attached to the knife ring. This automatic removal of ashes results in the regular feeding down of the fuel. The knife ring is held in position by guide rollers, and is geared on the inside through suitable gearing to an electric motor. The power required to rotate the knife ring (which makes about one revolution in 2 hours) = about 2 h.p.

A 10-feet diameter producer is designed to gasify 30 tons of nut size bituminous coal per day, and 25 tons of nut and pea coal mixed in the same period. A 7-feet diameter producer gasifying fine anthracite coal has a capacity of 7 tons per 24 hours. The "hot gas" efficiency of the producer is claimed to be 85 per cent., and the "cold gas" efficiency (with the gas cooled down to 75° to 80° F) = 80 per cent. The labour required per shift for a battery of 8 producers where the coal is delivered mechanically into the feeding apparatus, is as follows:—

1 man to control the working of the producers on top of staging.
1 man to remove ashes.
1 foreman.

The Hughes Producer.—The special feature of this producer is the use of a mechanical poker, which consists of a water-cooled steel casting suspended from

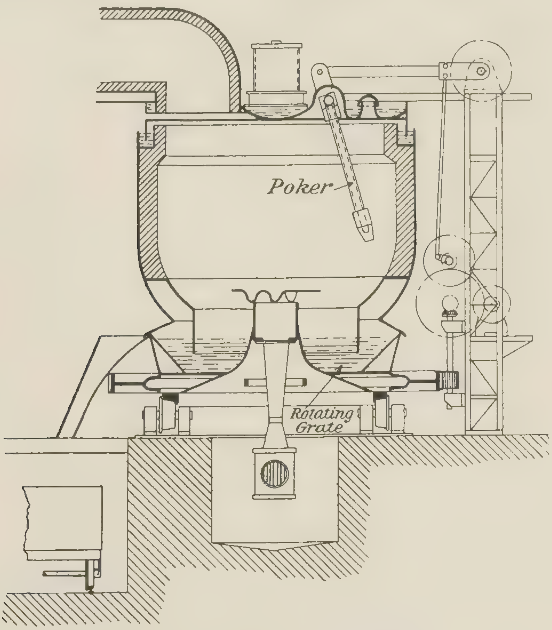


FIG. 195.—The Hughes Producer.

a trunnion and oscillated by an eccentric rod driven by mechanism from a main shaft. Fig. 195 shows a section through one of these producers. The shell is of the usual cylindrical form lined with firebrick, and connected with a cast iron base ring to which is bolted an ash receptacle forming a water-seal. The base rests upon a revolving turntable supported by conical rollers, so that the ash pan and producer shell with its fuel bed rotate together. The poker moves backwards and forwards radially while the producer revolves; consequently the fuel bed is broken up and the ash worked down for removal. The producer top is fitted with two feed hoppers, located at different distances from

the centre of the producer so that the coal is deposited in concentric rings on to the fuel bed below and levelled off by the poker. The main shaft and gearing are supported by a steel framework securely braced to the top of the producer, which consists of a flanged steel water-cooled casting forming a water-seal at the outer circumference of the producer cover. These producers are usually driven by a 3 h.p. motor.

Under average conditions, these producers are stated to gasify 25 lbs. of coal per hour per square foot of producer area; a 10-feet diameter producer has a nominal capacity of 1 ton per hour. Six men are required to operate a battery of 8 producers, where the coal is fed into the hoppers from overhead bins.

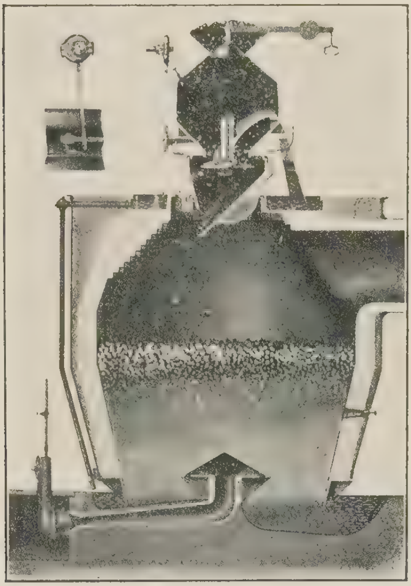


FIG. 196.—The Morgan Producer, with George Automatic Feed.

This producer is largely used in the U.S.A., where it was introduced, and gives most satisfactory results.

The Morgan Producer.—The Morgan producer is of the grateless bottom type in which the ash stands in a water-filled ash pan formed as a depression in the foundation. The producer itself consists of the usual cylindrical shell lined with firebrick, supported above the foundation by cast iron columns. Fig. 196 shows a sectional view of the arrangement. The top of the producer is covered by a shallow annular cast iron pan filled with water, through the central opening in which the feeding apparatus communicates with the interior. The feeding apparatus known as the "George Automatic Feeding Device" is the outstanding feature of the producer. It consists of an inclined water-cooled feeding spout which is slowly rotated under the overhead feeding hopper, and in doing so distributes the coal evenly over the fuel bed. This feeding device is made gas-tight between the top of the producer and the feeding hopper by means of water seals.

The working of the producer is controlled at the combustion zone through sight holes placed round the producer shell at a height of about 3 feet above the water-level in the ash pan, which is the height of the ashes in the producer. The amount of steam used is from 33 to 40 per cent. of the weight of the coal gasified. Working on bituminous coal containing about 10 per cent. ash and 1 per cent. sulphur, this producer is constructed to gasify about 10 lbs. of coal per hour per square foot of producer area. This may be increased to 12 or 15 lbs. per square foot per hour when using gas coal with high percentage of volatile matter and low ash content.

The following are standard sizes and capacities of the Morgan producer:—

Diam. inside firebrick lining.	Area of gas-making surface.	24-hour capacity with good coal.	Diam. of outlet.
6′ 0″	28 sq. ft.	4 tons	20″
8′ 0″	50 ”	7 ”	27″
10′ 0″	78·5 ”	10 ”	33″
12′ 0″	113 ”	15 ”	40″

The above capacities depend upon the kind of coal used. The following analysis of gas was obtained under ordinary working conditions from the Morgan gas producer using Illinois "New Kentucky" run of mine coal:—

Analysis of Coal.		Analysis of Gas.	
Fixed carbon	50·87 %	Carbon monoxide	24·5 %
Volatile matter	37·32 %	Hydrogen	17·8 %
Moisture	5·08 %	Hydrocarbons	6·8 %
Ash (with 1·12% sulphur)	6·73 %	Carbon dioxide	3·7 %
		Oxygen (free)	0·4 %
		Nitrogen	46·8 %

For working the producer, the following labour is required per shift :—

Plant of 2 producers—1 gas man and 1 labourer (latter half time).
" 3 " —1 " " 1 "
" 4 " —1 " " 2 labourers.

For larger plants, in addition to the gas man, one labourer is required for every three producers, and one ash man for every six producers. The above labour does not include that necessary for unloading the coal from the cars, which depends entirely upon prevailing conditions at the works.

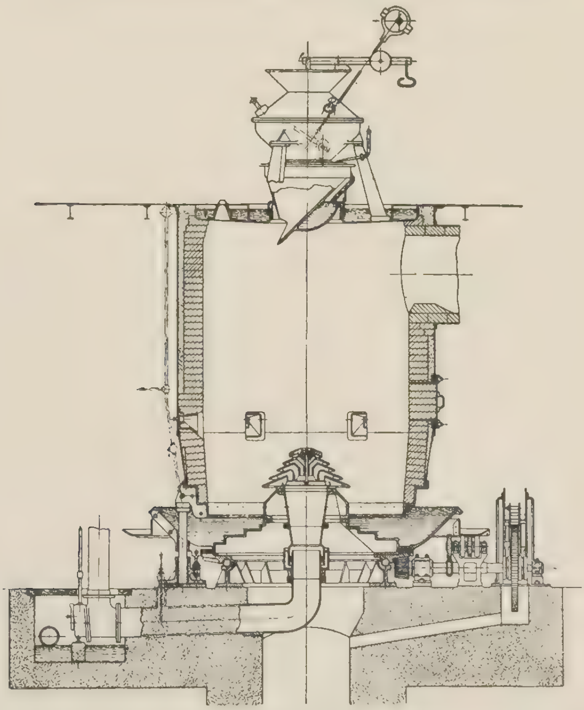


FIG. 197.—Morgan Producer with Rotating Grate and George Automatic Feed.

Fig. 197 shows the latest type of Morgan producer fitted with rotating grate.

The Talbot Producer.—The Talbot producer, illustrated in Fig. 198, retains the well-known features of the old type of producers with fixed grate,

but introduces a stirrer or rotary poker for maintaining a fuel bed of uniform level and density, and assisting the ashes in their descent. The stirrer is in the form of a crank, and rotates slowly with an up and down movement about its vertical arm or spindle which enters the top of the producer. The spindle and stirrer arm are water-cooled steel castings. It is stated that 28 to 30 tons of bituminous Durham coal can be gasified per 24 hours in a producer of this type 10 feet 4 inches diameter, giving good quality gas.

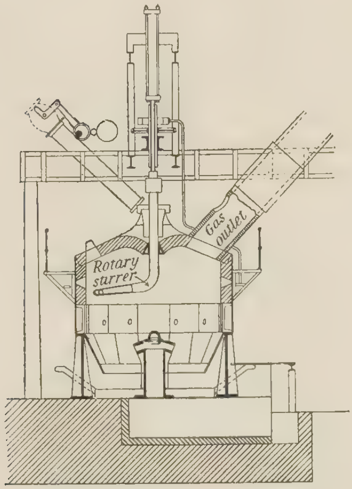


FIG. 198.—The Talbot Producer.

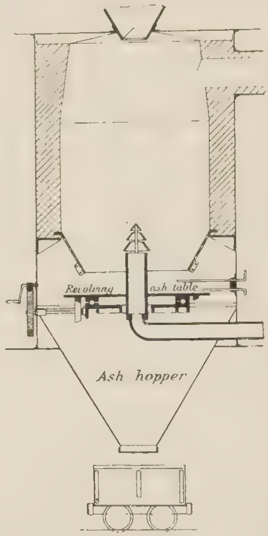


FIG. 199.—The Taylor Producer.

The Taylor Producer.—The Taylor producer, or, as it is often called, the "Wood producer," has as its distinctive feature a rotary ash table. Fig. 199 shows the arrangement adopted. The ashes fall on to a flat plate rotated by means of gearing, and from this grate the ashes fall into the funnel-shaped bottom of the producer, in which they are collected previous to being discharged through a sliding door into waggons below. This producer is understood to be the first to be fitted with a mechanical grate.

CONTINENTAL GAS PRODUCERS

The Goliath Producer.—This producer is designed for large capacities, and its arrangement will be seen from the sectional elevation shown in Fig. 200. Originally it was designed with the lower portion of the shell made to rotate in an opposite direction to the rotating grate, each portion being fitted with breaker knives for loosening the ashes and the coal and producing good quality gas rapidly. This design has, however, been modified, and the latest type is that shown in Fig. 200. It consists essentially of a cylindrical shell lined with firebricks, and at the bottom is an extension made of strong segment plates to withstand the crushing action on the clinker. The grate basin carries the grate body, which consists of a number of single rings provided with breaker knives and a number of openings through which the air and steam pass to the fuel bed. This grate basin is motor driven, and is rotated by means of a worm and wormwheel operated by a friction wheel and angle lever. The shell,

carried by four columns, is supported over the grate basin, and leakage of gas prevented by the water seal provided. The top of the producer is covered with a plate, in the centre of which is placed the feeding hopper, and round which are situated poking holes. These latter are fitted with steam seals to prevent gas from escaping when poking is being carried on. The air and steam enter through a tube beneath the grate support, which conducts the air under

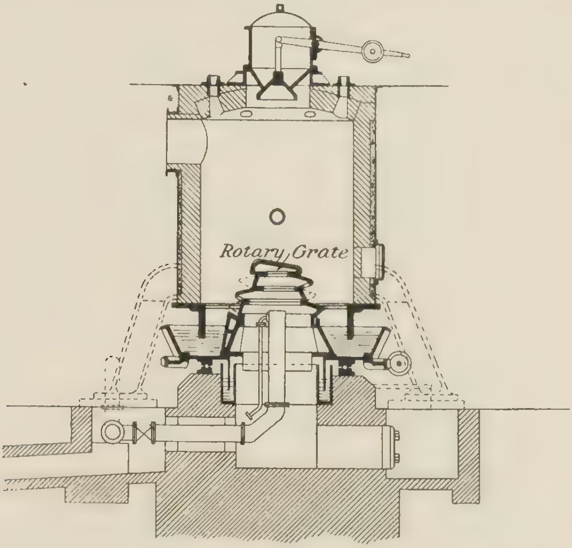


FIG. 200.—The Goliath Producer.

the grate, from which it passes to the fuel bed through the holes in the cast iron grate rings.

The producer is worked under an air pressure of 4 to 6 inches w.g. with steam injected as required. The pressure of gas at the outlet is about 1 to 1½ inches w.g. The grate basin makes about 4 to 5 revolutions per 24 hours, requiring about 2 h.p. for its rotation. According to the nature of the coal used the height of the fuel bed in the producer shaft is from 36 to 44 inches.

A producer of this type 8 feet 6 inches inside diameter, working with English and Westphalian coals in equal proportions, the former a rough non-caking coal giving about 10 per cent. loose ashes, and the latter (taken from the Dorstfeld mine) a caking coal with 7 to 10 per cent. ashes, has a capacity of about 25 tons per 24 hours. The following is an average analysis of gas produced during a period of one month in one of these producers installed at a steel works in Germany working on the above fuels.

CO_2	CO	H	Hydrocarbons	N
2·1 %	29·5 %	11·1 %	1·86 %	55 %

The cost of this size of producer completely mounted, erected, and lined with firebrick, but without motor or other power transmission, working platform or foundations, is approximately £800. Assuming normal conditions, the cost of producer completely connected up to power, air, and steam supply, gas flue, and with working platform and foundations would be approximately £1200.

This producer will supply a 40 to 50 ton open-hearth furnace producing

14 to 15 heats per week (*i.e.* about 675 tons of steel), using normal pig and scrap charges.

The Hilger Producer.—This producer, illustrated in Fig. 201, consists of a

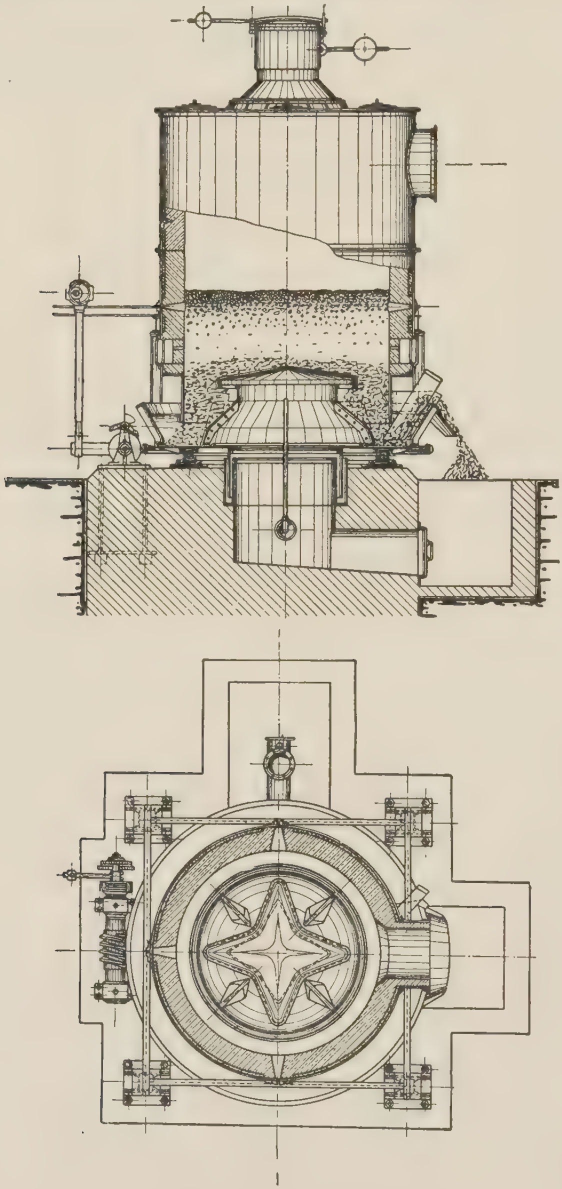


FIG. 201.—The Hilger Producer.

cylindrical shell lined with firebricks covered at the top and fitted with a double closing feeding hopper. The lower portion consists of a pan-shaped hearth rotated by means of worm gearing. On the hearth is fitted the grate, consisting

of two portions, the upper portion forming with the lower, a star-shaped downward-pointing opening which distributes the blast over the whole cross-sectional area of the producer. The hearth is rotated alternately forwards and backwards by means of a ratchet gear, giving a "pilgrim's step" movement. The amount of the forward and backward movements can be regulated, and the amount of ash thrown out altered to suit the kind of coal used. Fig. 202 shows a detail arrangement of this rotating gear. The feeding hopper illustrated in Fig. 203 is so arranged that if the counterpoise weight of the cone is lifted gently when the hopper is charged, the fuel falls into the middle of the producer as shown at "*a*," whilst if the counterpoise is lifted quickly the fuel is thrown towards the outside of the producer interior as at "*b*." The height of the fuel column is maintained at between 32 and 40 inches.

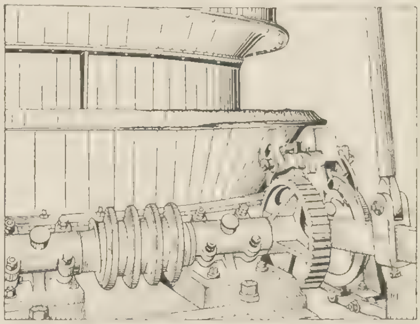


FIG. 202.—The Hilger Producer. Details of Grate Rotating Gear.

The following data refer to particulars of tests made on two Hilger producers fitted with revolving grates, each 8 feet 6 inches inside diameter, used for supplying gas to a 55-ton open-hearth furnace at the works of Dorman, Long & Co., Ltd., Middlesbrough. Duration of test: 12 working days. Coal used: 8 classes of English coal from the Durham district—Randolf coal, Lambton coal, Horden coal, Manisforth coal, Wheldale nut coal, Gordon house coal, Trimdon Grange coal, and Chilton coal. The average composition of the above is :—

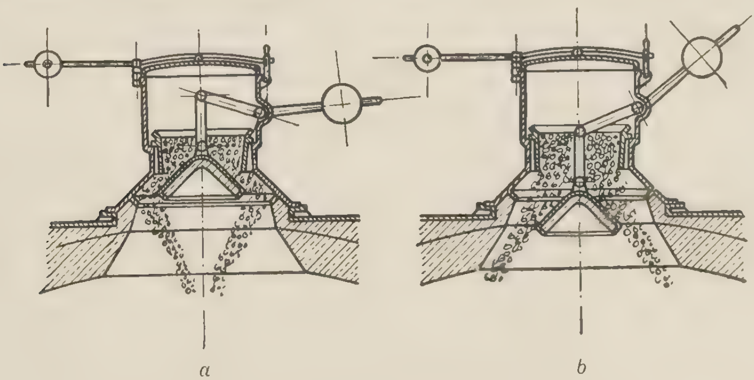


FIG. 203.—The Hilger Producer. Details of Feed Hopper.

Fixed carbon	54·7 %
Volatile matter	33·0 %
Moisture	2·8 %
Sulphur	2·3 %

Total carbon in coal, 75 per cent. Heat value of coal, 13,080 B.Th.U.'s per lb.

The average of 40 analyses of gas taken during the test was—

CO_2	CO	H	CH_4	N	Total combustible matter
2·3 %	30·0 %	10·4 %	2·9 %	54·4 %	43·2 %

The analysis of the ashes gave 93 per cent. ash and moisture, and 6·5 per cent. combustible matter, equivalent to 0·7 per cent. loss of combustible matter in the original fuel.

Sixty-four cubic feet of gas was obtained per lb. of coal, having a calorific value of 186 B.Th.U.'s per cubic foot. The temperature of the gas at the outlet of the producer was 625° C. and the gas pressure in the flue $2\frac{1}{2}$ to $3\frac{1}{4}$ inches w.g. The coal consumption per ton of steel produced was 464 lbs.

The approximate cost of one Hilger producer, 8 feet 6 inches inside diameter, is £650, or, including lining and erection, foundations, working platform, air, steam, and gas piping and valves, with coal bunker, £900 to £1000 according to conditions. The working costs of the producer are governed by the following :—

Power consumption of fan for air . . .	4 to 5 h.p.		per producer 8′ 6″ diam.
,, ,, for rotation of grate	0·7 to 0·9 h.p.		
Steam ,, 25 % by weight of fuel gasified			

Two producer men are required to work a battery of 3 producers per 12-hour shift, assuming that the coal is fed into the hoppers from overhead bins.

The Kerpely Producer.—The Kerpely producer, illustrated in Fig. 204, has a grate of the revolving type, consisting of a single cone fixed eccentrically

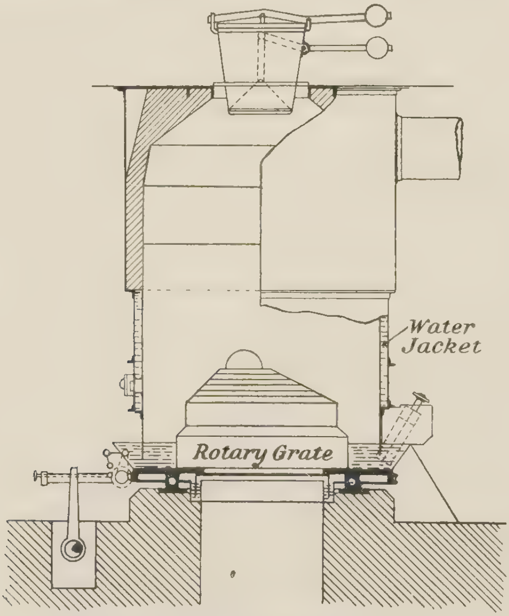


FIG. 204.—The Kerpely Producer.

with the producer shell and provided with a flat top. This cone consists of a number of plates through which air is delivered to the producer and dispersed over the fuel bed. The ashes which accumulate in the water-cooled trough

are automatically discharged by an adjustable fixed scraper as the trough rotates.

The grate is revolved at a speed of about 1 revolution every $2\frac{1}{2}$ to 3 hours, requiring approximately 2 h.p. for driving it. The number of men required to work these producers varies considerably, according to the class of coal being gasified. In some cases where highly coking fuel is used, one man per shift is required for each producer. In one case where free burning fuel is used, two men only are employed per shift on a battery of 8 producers equipped with overhead feed for the hoppers and mechanical ash delivery. In another case, a battery of 22 producers fitted with hoppers fed from bunkers and overhead cranes, and where ash is also removed by the same cranes, there are employed :—

$$\left.\begin{array}{l}\text{1 foreman . . . .}\\ \text{2 chargers . . . .}\\ \text{2 crane drivers . . . .}\\ \text{1 labourer to clean and lubricate driving machinery}\end{array}\right\}\text{ per shift.}$$

This plant gasifies 380 tons of coal per 24 hours.

The Rehmann Producer.—The Rehmann producer, shown in Fig. 205, is similar to the Kerpely, but differs in respect to the construction of the grate.

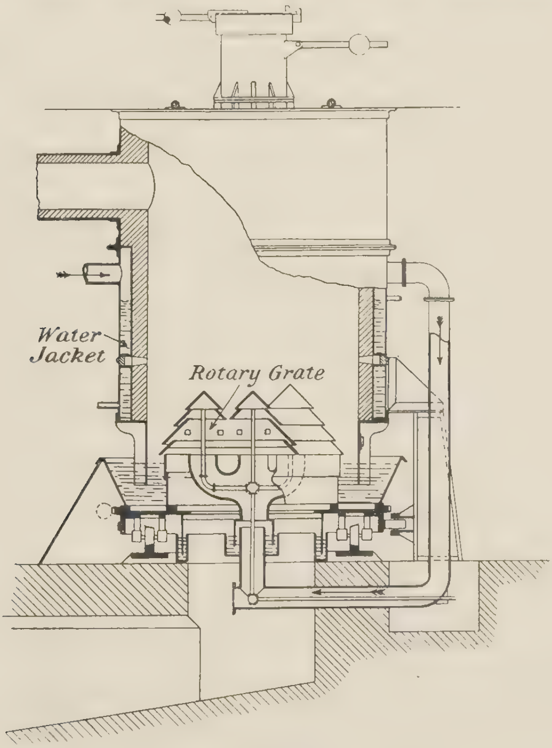


FIG. 205.—The Rehmann Producer.

The grate of the Rehmann producer consists of several cones, which tend to loosen the mass of coal during its downward movement. The grate is of the revolving type, and air is admitted through covered openings in the cones, each

cone being supplied with air by a separate pipe. The lower part of the producer casing consists of cast iron removable segments to facilitate repairs and cleaning.

Rehmann producers are made in sizes varying from 6 to 10 feet inside diameter, the largest size having a capacity of 12 to 22 tons of nut coal per 24 hours. The following are two average analyses of gas produced from coal the analyses of which are given :—

	Analysis of Coal.		Analysis of Gas.	
(1)	C	63·67 %	CO_2	3·25 %
	Volatile matter .	28·67 %	CO	28·7 %
	Ash	6·37 %	H	8·7 %
	H_2O	1·19 %		

Test on briquettes of brown coal from Grehlwerk :—

	Analysis of Coal.		Analysis of Gas.	
(2)	C	37·29 %	CO_2	3·2 %
	Volatile matter .	50·20 %	CO	30·6 %
	Ash	5·39 %	H	14·2 %
	H_2O	12·51 %		

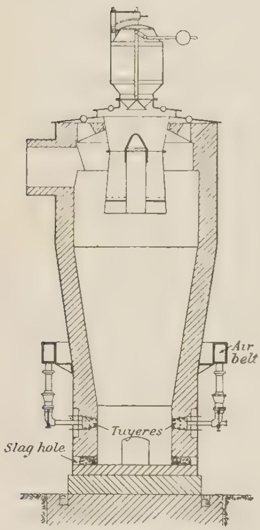


FIG. 206.—The S. F. H. Producer.

The S.F.H. Producer.—The S.F.H. producer, which is being developed on the Continent, was introduced by Sepulchre, Fichet, and Heurtey, and is a return to the principle of the Ebelmann producer. As will be seen from the sectional elevation shown in Fig. 206, the producer resembles a charcoal blast furnace, and consists of a shell lined with firebrick with a solid hearth, which acts as a receiver for the molten slag formed during working. Two tapping holes situated opposite one another, just above the bottom of the hearth, serve for the removal of the slag, and situated above is a row of water-cooled tuyeres three to six in number, connected with a blast main which encircles the producer. The coal fed into the producer is mixed with limestone, sand, or granulated blast furnace slag for the purpose of liquifying the ash and producing, under the influence of the air blast, a molten slag which is tapped from the producer every one or two hours. No steam is used with the air blast, which is supplied to the producer at a pressure of from $\frac{3}{4}$ to $2\frac{1}{4}$ lbs. per square inch. Consequently the hydrogen content in the gas produced is low, as will be seen from the following table :—

TABLE LXXXIII

ANALYSES OF GAS PRODUCED IN THE S.F.H. PRODUCER

	Lignite.	Brown coal.	Coal.	Coke briquettes.
CO	29·5	28·3	31·0	27·9
H	6·7	7·7	6·0	1·2
CH_4	3·2	7·5	6·5	2·0
CO_2	2·5	1·4	1·0	1·6
N	58·1	55·1	55·0	67·3

The gasifying capacity of this producer is given as 175 to 220 lbs. of coal per square foot of grate area per hour, and it is claimed that a producer only 4 feet diameter inside the brickwork will gasify 24 tons of average quality coal every 24 hours. The rapid working of the producer has its effect on the brickwork lining in the hearth portion, which requires to be renewed every 3 months. The shaft portion of the brickwork is expected to last for several years.

Cost of Gas Producing

The following costs have been prepared from particulars of several producers, representative of the leading types, and have been based on a producer plant supplying gas to a 60-ton open-hearth furnace working with cold pig and scrap charges, producing 13 heats per week. Output of furnace therefore equals 780 tons weekly.

Cost of Producer Plant.—Two 8 feet 6 inches diameter producers of several makes would supply sufficient gas for the above, and the cost of the plant erected and set to work would be approximately £2000. This figure does not include overhead storage bins for the coal, or mechanical handling plant.

Allowing 10 per cent. for depreciation and 5 per cent. for interest, the annual charge on £2000 = £300. Assuming that the producer plant is worked for 48 weeks per year supplying gas, the output of the furnace plant supplied in that time would be 780 × 48 = 37,440 tons of liquid steel. ∴ Charge for depreciation and interest on producer plant per ton of liquid steel $= \frac{300 \times 240}{37{,}400} = 2d.$

Cost of Fuel.—Taking an average of 5 cwt. of coal per ton of liquid steel tapped from furnace, and assuming the coal to cost 8*s.* per ton delivered at the plant, the cost of fuel per ton of liquid steel $= \frac{5}{20} \times 8 = 2s.$

Cost of Labour.—Assuming normal conditions and on the understanding that the coal is fed into the producer hoppers by hand, one gas man and one labourer per 12-hour shift could do all the necessary work. The weekly wages paid to both night and day shift men amount to £5 13*s.* Adding 50 per cent. for management expenses, the cost of labour on the producer plant per ton of liquid steel produced

$$= \frac{£5\ 13s. + £2\ 16s.\ 6d.}{780} = \frac{£8\ 9s.\ 6d.}{780} = 2\tfrac{1}{2}d.$$

Cost of Repairs, Power, Steam, Stores, etc.—These items are all small, and the total cost taken over a period should not exceed about $2\frac{1}{2}d.$ per ton of liquid steel.

Summary of Costs

	s.	*d.*
Depreciation and interest on plant	0	2
Cost of fuel	2	0
Cost of labour	0	2½
Cost of repairs, power, steam, stores, etc. .	0	2½
∴ Cost of gas production per ton of liquid steel =	2	7

Or, excluding the cost of fuel, the cost incurred in producing gas = 7*d.* per ton of liquid steel.

The cost of the producer plant does not influence considerably the cost of

the steel produced. It is, therefore, advisable before installing plant to ensure that the most economical and efficient producer is adopted, since a saving in the coal bill (which is by far the largest item of cost) often more than compensates for the increased cost of plant.

Cost of Gas Producing in Large Open-hearth Plant.—Where a battery of gas producers is installed to work in conjunction with several open-hearth furnaces, it often pays to instal a complete coal-handling plant, so that the labour required to work the producers may be reduced to a minimum. A typical plant is described and illustrated on p. 327. The increased cost of the plant will be more than compensated for by the saving in labour effected.

Taking the charge for depreciation and interest on a large plant equipped with coal handling to be $2\frac{1}{2}d.$ per ton of steel produced, and the fuel consumption at 5 cwts. of coal per ton of steel (which with coal at 8*s.* per ton = 2*s.*), the cost of labour in working the producer plant is equivalent to from $\frac{3}{4}d.$ to 1*d.* per ton of steel, and the cost of repairs, power, steam, stores, etc. = $2\frac{1}{2}d.$ per ton.

$\therefore$ Cost of gas producing per ton of liquid steel = 2*s.* 6*d.*, or a saving of 1*d.* per ton of steel by installing mechanical handling plant.

Cost of Gas Producing in Small Open-hearth Plant.—Naturally the cost of producing gas for a small open-hearth plant is considerably greater than for a large plant. Not only is the cost of labour per ton increased; the fuel required to produce 1 ton of steel is increased as well. In the case of a 10-ton open-hearth furnace (where the outlay on the gas producer plant with accessories is from £300 to £400), allowing for a coal consumption of 9 cwts. per ton of steel produced and with coal at 10*s.* per ton, the cost of gas producing per ton of liquid steel = 5*s.* 6*d.* to 6*s.*

Theory of Gas Producing

Theoretically the most economical method of utilising the heat in coal is by direct firing. Unfortunately, the heat energy contained in coal is not all imparted to the material in the direct-fired furnace, and generally the process is much less economical than when gas, previously generated from coal in a producer, is employed. Moreover, gas firing has several distinct advantages over direct coal firing, inasmuch as gas-fired furnaces can be more easily controlled, and the flame can be made more or less oxidising as required. But, more important still, direct coal firing is impracticable in open-hearth furnace practice. This is the reason why Siemens', when developing their open-hearth furnace, introduced at the same time a commercial type of gas producer, since gaseous fuel, burnt in the furnace with air, enabled them to obtain the required temperature with the aid of regeneration.

Reactions in Gas Producers.—The working of a gas producer depends upon the passage of air or air and steam through a mass of incandescent fuel. This first results in the production of carbon dioxide (CO_2), caused by the combination of the oxygen in the air blast with the carbon in the fuel, and as this passes up through the incandescent coal, the CO_2 is converted into carbon monoxide (CO) by further combination with more carbon. If steam is used with the air, additional reactions take place, resulting in the splitting up of the steam (H_2O) into hydrogen and oxygen. Some of the hydrogen combines with carbon to form hydrocarbons, and the remainder passes off with the gases as hydrogen gas. The oxygen set free by the breaking up of the steam, unites with the carbon to form CO_2 and finally CO in passing through the fuel. The nitrogen from the air which is set free mixes with the carbon monoxide and hydrogen, and passes out as an inert gas to the furnace. The volatile matter and moisture contained

in the coal are driven off before the fuel reaches the incandescent zone and mix with the other gases, while the ashes and some of the sulphur work down through the producer and are withdrawn at the bottom in the form of ashes and clinker.

Some of the sulphur contained in the coal passes out with the gas, and thence to the furnace. Since this is a most objectionable element in the steel, care should be taken that the fuel used is as free as possible from sulphur. In some cases lime is added with the coal in the producer in order to make a more fusible clinker, which will carry down with it as much sulphur as possible.

The use of air without steam in the producer gives rise to undesirably high temperatures, besides increasing the amount of clinker. It is, therefore, found necessary to introduce a steam jet with the air. When carbon burns to CO_2 the reaction is exothermic, *i.e.* heat is evolved, and when CO_2 is converted to CO the action is endothermic, *i.e.* heat is absorbed. In the first case 1 lb. of carbon burnt to CO_2 evolves 14,500 B.Th.U.'s, and when this quantity of CO_2 thus formed combines with more carbon to form CO 10,090 B.Th.U.'s are absorbed. Thus 4410 B.Th.U.'s are given off as heat to the fuel. If this action were to continue heat would accumulate in the producer too rapidly to be dissipated by radiation and other losses, and the producer would consequently be overheated. To maintain the temperature to a bright red heat and diminish the quantity of nitrogen which must of necessity be carried in with the air, steam is blown in with the air. The breaking up of steam into its components, hydrogen and oxygen, takes up heat from the incandescent fuel, and care must be exercised not to introduce too large a quantity of steam or the temperature will be reduced below working limits. The amount of steam introduced into producers worked without recovery of ammonia is about 33 per cent. of the weight of the fuel gasified, and the weight of air about four times the weight of fuel gasified.

Efficiency of Gas Producers.—This can be best expressed as the ratio of the heat units contained in the gas generated in the producer to the heat units contained in the coal used for gasification. (To the latter must also be added the heat units in the steam, if steam is blown in with the air.) The losses in producers may be classified as follows:—

(1) Loss of sensible heat in gases.
(2) Heat lost by radiation from producer.
(3) Heat carried away by ashes and unconsumed carbon in ashes.

With the object of checking the working of gas producers several different types of apparatus have been devised, which, when applied, will indicate in one way or another the efficiency of the gas-producing plant. A CO_2 recorder of the registering type will give a continuous record of the percentage of CO_2 in the producer gas, and since the presence of CO_2 indicates either the burning of CO in the producer or the incomplete production of CO, a measure of the efficiency from this standpoint can be obtained. Similarly, a recording pyrometer placed near the outlet will indicate the temperature of the gas and show if the producers are being operated properly. Further, an automatic and continuous register may be taken of the calorific value of the gas produced. Fig. 207 is a reproduction of a chart taken from a Beasley's recording gas calorimeter installed in connection with a Wilson gas producer plant showing a one day's run. Apparatus such as this affords valuable indications of the efficiency of the producer plant. In addition to these automatically and continuously recorded tests, the quality of the gas and efficiency of the producer plant may be obtained by analysis, which, however, necessitates taking samples of the gas systematically and having them analysed. If analysis of gas is done in conjunction with a systematic analysis of the coal used and the ashes produced, an accurate record of the efficiency of the producer plant is obtained,

the cost of obtaining which would be found in most cases to be more than counterbalanced by the economy effected in working.

For complete determinations of producer efficiencies reference should be made to standard text-books on fuels and metallurgy, and to an interesting paper on "The efficiencies of gas producers," by Mr. C. F. Jenkin.[1] In Mr.

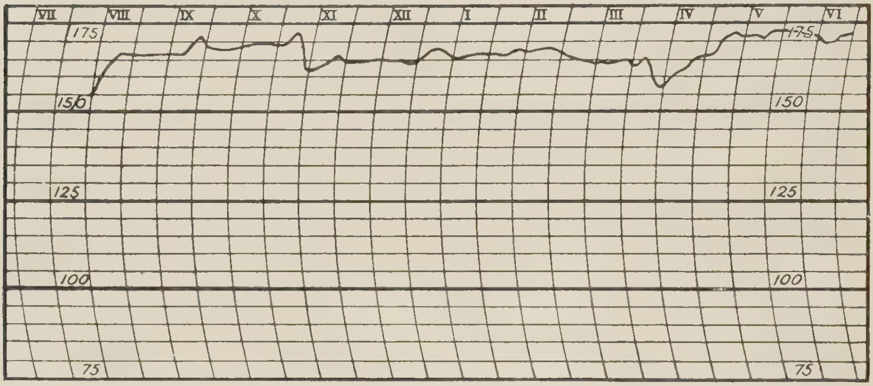


Fig. 207.—Chart showing Calorific Value of Gas.

Jenkin's paper a formula is given by the aid of which the efficiency of a gas producer can be determined.

If M = the heat of combustion of the gas per kilogram of carbon contained in it.

K = the proportion of carbon contained in the coal.

G = the proportion of carbon which is made into gas.

H = the heat of combustion of 1 kilogram of coal.

$$\text{Then cold gas efficiency} = \frac{M \times K \times G}{H}.$$

The author calls "M" the "Figure of Merit" of the gas, and gives typical calculations for obtaining the value of M. When the gas from the producer is used "hot," the above efficiency is converted into a "hot-gas efficiency" as follows:—

Hot gas efficiency

$$= (\text{cold gas efficiency}) \times \left(1 + \frac{\text{Sensible heat per cubic metre of the gas}}{\text{Calorific power of the gas}}\right)$$

The sensible heat per cubic metre of gas = {(temperature of gas − temperature of atmosphere) × the "volumetric specific heat" of the gas}. The volumetric specific heat of producer gas is usually betwen 0·31 and 0·33. Since gas from a producer working under good conditions is usually at a temperature of about 650° C. (1200° F.), the hot gas efficiency of a producer is about 12 to 14 per cent. higher than the cold gas efficiency.

The most accurate way to determine the efficiency of a producer would be to measure the quantity of gas made from a known weight of coal and burn samples of the gas and coal in a calorimeter. The efficiency would then be given as—

$$\frac{\text{Calorific value of gas per c. ft.} \times \text{No. of c. ft. of gas produced per lb. of coal}}{\text{Calorific value of coal per lb.} + \text{heat put into producer by steam per lb. of coal}}.$$

[1] "Proceedings Institution of Civil Engineers," vol. cxxiii., pp. 328–351.

The amount of gas produced can be measured by means of a Venturi or other type of meter, or it may be determined by calculation from the analysis of the gas.

Taking the calorific value of the coal at 13080 B.Th.U.'s per lb., the heat put into the producer per lb. of coal = 13,080 + the heat value of the steam used per lb. Assuming that 33 per cent. by weight of steam is added per lb. of coal, and that the steam contains $1155 - 62 = 1093$ B.Th.U.'s per lb., the heat imparted to the producer by the steam $= \frac{33}{100} \times 1093 = 360{\cdot}7$ B.Th.U.'s per lb. of coal.

$\therefore$ Total heat put into producer $= 13{,}080 + 360{\cdot}7 = 13{,}441$ B.Th.U.'s per lb. of coal.

Assuming that 55 cubic feet of gas are produced per lb. of coal, and the calorific value of the coal gas = 186 B.Th.U.'s per cubic foot, the heat units in the gas given off from 1 lb. of coal $= 55 \times 186 = 10{,}230$ B.Th.U.'s.

$\therefore$ Cold gas efficiency of producer $= \frac{10230}{13441} = 76$ per cent.

The "hot gas" efficiency of the producer, which is actually the real efficiency of the producer, since it takes into account the sensible heat of the gas, is determined by adding to the available heat units in the cold gas the sensible heat. Assuming the gas to leave the producer at 1200° F., then the sensible heat per lb. of gas $= (1200 - 62) \times$ specific heat of gas, which we will assume $= 0{\cdot}33$.

$\therefore$ Sensible heat $= 1138 \times 0{\cdot}33 = 375{\cdot}5$ B.Th.U.'s per lb. of gas.

1 lb. of the gas under consideration would = about 14·5 cubic feet at 62° F.,

$\therefore$ sensible heat in gas per cubic foot (referred to 62° F.) $= \dfrac{375{\cdot}5}{14{\cdot}5} = 26$ B.Th.U.'s

$$\therefore \text{ Hot gas efficiency of producer} = \frac{(186 + 26) \times 55}{13441} = 87 \text{ per cent.}$$

Blast-Furnace and Coke-Oven Gas.—Up to the present time, blast-furnace and coke-oven gases have not been utilised to a great extent for melting purposes in open-hearth furnaces. Experiments have, however, been made from time to time with a view to their adoption in place of producer gas; and whereas some works report failure, others appear to be carrying out the experiments with success. It would seem that either gas used alone is not suitable, and experience obtained in the trials points to the advisability of mixing the gases either together or with producer gas.

Experiments carried out at the Friedrich-Wilhelmshütte at Mülheim Ruhr[1] show that although it is possible to use blast furnace gas alone, the process of steel making takes more time than when producer gas is used. Consequently coke-oven and blast-furnace gases are mixed, usually in the proportion of 1:4. The mixing of the gases takes place before they enter the distributing valve. These experiments have been tried on two acid open-hearth furnaces of 12 and 15 tons capacity respectively.

At the works of Hubertushütte,[2] coke-oven gas has been used for open-hearth furnace practice with success. It is stated, however, that the durability of the furnace roof and linings has diminished 8 to 10 per cent., but the checker work in the regenerators lasts 40 to 60 per cent. longer.

Natural Gas.—Natural gas has been in use in the United States since 1884 for open-hearth furnaces as well as for heating and lighting purposes. It has also been adopted to a considerable extent in gas-fired crucible steel furnaces. The large resources so long drawn upon, give evidence of supplying the increasing demand for many years to come, and with the opening up of new oilfields,

[1] "Stahl und Eisen," vol. 31, pp. 1295–1301.
[2] "Iron and Coal Trades Review," vol. 80, p. 123.

new resources of gas supply become available, natural gas usually existing in the vicinity of oilfields. The gas, which issues from the earth at varying pressures up to about 200 lbs. per square inch, facilitates its distribution, being carried in pipe lines for great distances from its source to the steelworks. As an instance of the quantities available, it may be stated that in 1906 the production of natural gas in the U.S A.[1] was 388,842,562,000 cubic feet, measured at atmospheric pressure, its estimated value being £9,765,402. The gas is delivered at the works in the Pittsburg district for 6*d.* to 7*d.* per 1000 cubic feet (1912 prices).

A typical analysis of Pittsburg Natural Gas is given below[2]:—

Methane marsh gas	67·0 %
Hydrogen	22·0 %
Ethane (C_2H_6)	5·0 %
Ethylene (C_2H_4)	1·0 %
Carbon monoxide	0·6 %
Carbon dioxide	0·6 %
Nitrogen	3·8 %

Many steelworks in the U.S.A. have their batteries of producers standing idle for considerable periods, and only put them into use when the supply of natural gas fails, or the price is raised above that at which producer gas can be made.

The relative values of producer gas and natural gas are given below. The heat value of 1 lb. of average Pittsburg coal is given by the Morgan Construction Co. as equal to that contained in about 12½ cubic feet of natural gas obtainable in the same district. Allowing for a producer cold gas efficiency of 76 per cent., the gas produced from 1 lb. of coal is equivalent to 9·5 cubic feet of natural gas, assuming that both gases can be utilised with equal economy in the furnace. Taking the cost of labour, maintenence, depreciation, etc., on a gas producer plant at 1*s.* 1*d.* per ton of coal gasified, the following figures give the corresponding costs of coal and natural gas.

Cost of coal per ton	3*s.*	4*s.*	5*s.*	6*s.*	7*s.*	8*s.*	9*s.*	10*s.*
Equivalent cost of natural gas per 1000 cubic feet	2·30*d.*	2·87*d.*	3·43*d.*	3·99*d.*	4·56*d.*	5·12*d.*	5·69*d.*	6·25*d.*

That is, when the price of 1000 cubic feet of natural gas exceeds 3·99*d.* and coal per ton remains at 6*s.*, it is cheaper to use coal as far as fuel is concerned.

In Canada, large supplies of gas are being discovered and utilised for power and lighting purposes, and with the development of the steel industry in that country, natural gas will no doubt be of great service.

In the Russian oilfield areas, natural gas abounds, but its use in the steel industry must necessarily be a restricted one owing to the smallness of that country's output of steel. An analysis of natural gas at Bibi-Eibat, Russia, is given below:—

	Depth of bore hole—2106 feet.
CO_2	3·0 %
Heavy hydrocarbons	1·2 %
O	7·0 %
Methane	54·8 %
H	13·6 %
N	20·4 %

[1] "Engineering," vol. 85, p. 32.

[2] Brislee, "Industrial Chemistry," p. 159.

The apparent lack of natural supplies of gas in this country demands all the more attention to the development and perfecting of the gas producer, and the complete utilisation of gases from blast furnaces and coke ovens, in order that British manufacturers may be placed in a position to meet the competition of more favoured countries. That natural gas does exist in England is proved by its discovery at Heathfield, Sussex, where it is obtained at a pressure of 200 lbs. per square inch.[1] As long ago as 1887, natural gas was being used for boiler firing at the Hebburn Colliery near Newcastle,[2] but whether these are simply isolated cases or an indication of the presence of valuable supplies in this country, has still to be determined.

Water Gas.—The experiments which have been made with water gas for melting in open-hearth furnaces do not appear to favour the adoption of water gas plants. The Dellwik-Fleischer water gas plant, which has come to the front during recent years, gives a gas of the following average composition :—

H	49 %
CO	39 %
CO_2	5 %
Methane	0·7 %
Nitrogen	6·3 %

An English firm is stated[3] to have used a mixed water gas for steel-melting purposes with good results, and Nydgvist and Holm, Trollhättan, Sweden, have been working two furnaces of 5 and 8 tons capacity satisfactorily with Dellwik-Fleischer gas. The chief objection to water gas is the intense heat developed by its combustion, and the consequently more rapid destruction of the furnace lining.

The ordinary producer gas still maintains its premier position as the source of heat for open-hearth furnace working, and until some distinct economy or advantage is shown by other forms of gas or methods of heating, the gas producer is not likely to suffer much serious rivalry.

[1] "Journal Iron and Steel Institute," 1903, II, p. 580.
[2] "Journal West of Scotland Iron and Steel Institute," vol. I, p. 117.
[3] "Stahl und Eisen," vol. 27, pp. 1181–1187 and 1223–1228.

CHAPTER XXXII

ARRANGEMENT OF LARGE OPEN-HEARTH FURNACE PLANTS IN STEELWORKS

THERE are certain determining factors which naturally suggest and often compel a definite arrangement of the different parts of a steelworks plant. In large open-hearth plants steel may be manufactured by any or all of the following methods :—

1. Melting and converting materials from the cold state into steel in fixed or tilting open-hearth furnaces.
2. Melting and converting proportions of cold scrap and liquid iron into steel in fixed or tilting open-hearth furnaces.
3. Converting molten iron into steel in fixed or tilting furnaces.
4. Refining molten metal (partially converted to steel by other means) in fixed or tilting furnaces.
5. Partially converting iron to steel in fixed or tilting open-hearth furnaces, and afterwards refining in electric furnaces.

Therefore, the process or method of manufacture to be conducted determines in some degree the kind of plant required and its arrangement. In the case of method (1) there is no necessity to have a blast furnace or pig-iron mixer, but in working the other processes the pig iron must be taken either direct from the blast furnace to the open-hearth furnaces or to mixers, and from thence to the open-hearth furnace. To remelt the pig iron in cupolas before use in the open-hearth furnace is not usual or economical.

Generally considered, the arrangements of plant necessary for producing steel by the various processes conducted in the open-hearth furnace, can be reduced to two :—

1. For dealing with materials in the cold state and melting and converting them to steel.
2. For converting and refining materials in the molten state to steel.

There are other considerations which naturally enter into the design and arrangement of steelworks after the method of manufacture has been decided, and some of these are :—

1. The relation of the steel melting and casting buildings to railways and various sidings and works track for the supplies of raw materials, and to the mills to which the ingots produced are to be taken.
2. The relation of the blast furnaces to the mixers.
3. The relation of the mixers to the open-hearth furnaces.
4. The means of transport of materials from scrap yard to furnaces, from blast furnaces to mixers, and from mixers to the open-hearth furnaces.
5. The means of handling the steel produced in the open-hearth furnaces, and the removal and disposal of slags.
6. The relation of the fuel supply to the open-hearth furnaces and mixers, and the handling of coal and ash at the gas producers.

In new works, where every opportunity is given to the engineer to instal the best steel-making plant without any limitations of site or expense, it is a

comparatively easy matter to make an efficient lay-out for the particular kind of product and amount of output required. A more difficult problem, however, is that of converting old works to new, where the limitations of site and money interfere with the execution of the best rearrangement.

Open-hearth Plant using Cold Charges.—In America and Germany, where the natural resources favouring a greater steel production exceed those of England, there is more scope and inducement to develop new and remodel old steelworks, with the result that steel can be produced more rapidly and at less cost. Take, for instance, the rate of output on the Continent from fixed open-hearth basic furnaces of from 30 to 40 tons capacity melting and converting cold charges to steel, and compare the output from furnaces of the same nominal capacity producing ingots for the same purpose in Britain; it will be found that about double the output is obtained from the Continental steel furnaces. The facts are, that on the Continent, 4 heats are usually obtained (and sometimes 5 heats) per day of 24 hours from furnaces of the above capacity. In Britain, a good average number is 2 heats per 24 hours. Mr. B. W. Head states[1] that in South Wales, where they melt a great deal of scrap and work mostly on the acid process, they consider 12 heats per week extremely good working, and this we have confirmed from other sources. Even in Italy, at the Siderurgica di Savona, where they make tin plates, they get from 4 to 5 heats per day out of 25-ton furnaces, and the mechanical arrangements for handling the materials are not good.

While the arrangement of works, the facilities for handling, removing, and charging raw materials, and the design of furnaces, are largely responsible for greater outputs, other factors contribute also to the higher production of steel, such as hastening the operations of charging, melting, tapping, slagging, and patching the furnace hearth between heats.

The campaign of a continental furnace is short compared with that of British furnaces, the number of heats obtained being from 300–350, but with an installation of five furnaces, four can be kept in regular commission all the year round, one always being under repair by an expert repairing gang kept in constant employment. It is found, therefore, more economical to work on this principle than to keep patching the furnaces weekly for a longer period on commission on a gradually diminishing output.

Handling Materials.—The usual arrangement of the modern steelworks where cold charging is conducted, consists of a number of furnaces in one line, with the casting shop on one side and the charging platform on the other, suitable cranes spanning each bay. On the charging platform, charging machines suspended from overhead gantries such as illustrated in Fig. 208, or machines of the low ground revolving type which run on a broad gauge track on the platform, are used for rapidly filling the furnaces.

In the scrap yards adjoining the furnace building, overhead electric travelling cranes with suspended magnets empty scrap and pig iron from railway trucks, and from the scrap and pig iron heaps fill the pans, which are conveyed on trucks to the charging platforms to be handled by the charging machines. Where a large proportion of scrap is used in the charges, it is found more economical to purchase scrap in bundles or to do the bundling in scrap presses in the stock yard. The practice in all countries is much alike in this respect, although the arrangements and conveniences for handling the materials may differ.

Arrangement of Open-hearth Furnace Plants using Molten Pig Iron Charges.—During recent years, the introduction of molten pig iron charges in

[1] "Recent Developments in Steel-Works Practice," "Journal West of Scotland Iron and Steel Institute," 1911–12, pp. 14–15.

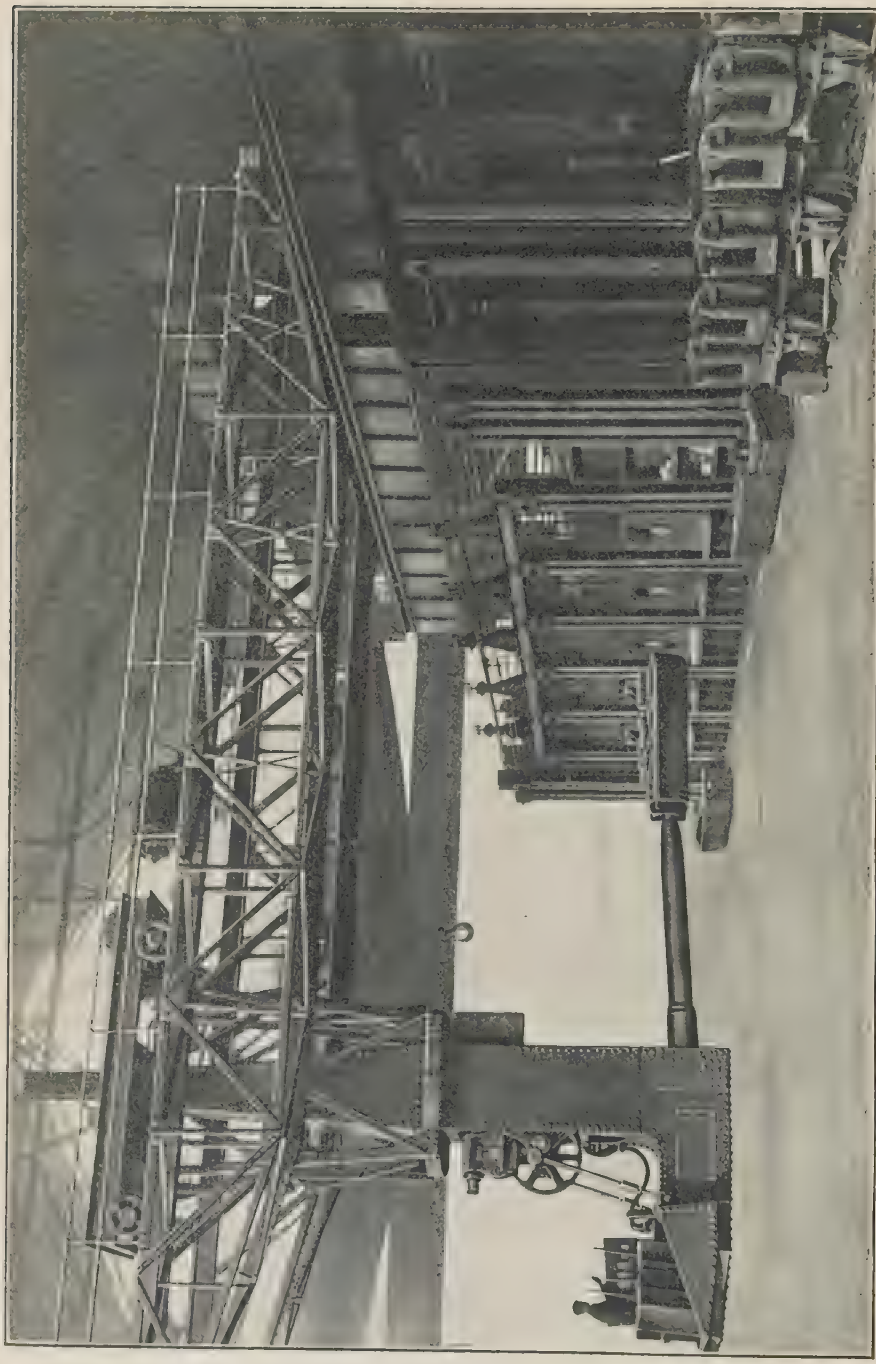


FIG. 208.—Wellman Charging Machine.

open-hearth furnace practice has caused a considerable amount of change in the design of new steelworks and in the remodelling of old steelworks. Several processes of manufacture are conducted in open-hearth furnaces with partially or entirely molten metal charges, which necessitate the use of slightly different plant for handling the materials in each case, but the outstanding features in the rearrangements consequent on the introduction of molten iron charges are the employment of blast furnaces and mixers, with the auxiliary plant required in conveying the molten metal to the mixers, and from them to the furnaces.

In some works the metal is conveyed direct to the open-hearth furnaces from the blast furnaces, but this practice is becoming the exception.

Position of Blast Furnaces.—It is not essential that the blast furnaces should be in close proximity to the mixers—as a rule they are some distance from them. In some cases the metal is carried for several miles in ladles mounted on locomotive trucks, when the blast furnaces are not in the immediate neighbourhood of the steelworks. There is, of course, a danger of the metal "skulling" in the ladle, but when the transit of the metal is carried out expeditiously, this is comparatively slight.

Position of Mixers.—No fixed plan is adopted in the arrangement of mixers in relation to the furnace plant. Usually, the mixers are placed in the same building as the furnaces, and in line with them, so that the charging machines and overhead cranes may serve both the mixers and furnaces. In other works, the mixers are placed in the same building as the open-hearth furnaces, not in the same line, but opposite and parallel with them. Then again, mixers are sometimes arranged in separate buildings entirely from the furnaces but adjacent to them. This latter arrangement is convenient when mixers are used for serving furnaces in different buildings. The question of position is determined by the requirements of the furnaces, and the best means of receiving the metal from the blast furnaces and distributing it to the melting and converting furnaces.

Auxiliary Handling Plant.—Molten metal charges are invariably brought to the mixers from the blast furnaces in steam or electrically driven locomotive ladle trucks. The metal, after being weighed on a weighbridge, is tipped into the mixer by a hydraulic or electrically driven tipping device, or by overhead crane. The metal is likewise conveyed from the mixers to the furnaces, and is usually poured into the latter while the ladle is suspended from the overhead crane, the tipping being performed by an auxiliary crab on the crane.

Charging machines are used just as in furnace plants where cold metal charges are melted, but they are principally required for charging ore, lime and scale, and also scrap, when proportions of scrap steel are used with the molten metal charges.

Typical Modern Equipped Open-hearth Steelworks

In this country many steelworks adopted the molten metal process several years ago. The Frodingham Iron & Steel Co., The Cargo Fleet Co., and more recently the Skinningrove Iron & Steel Co. have installed the Talbot Continuous Process.

A few years ago the Glengarnock Iron & Steel Co.'s Works in Ayrshire were remodelled by Mr. Edgar W. Richards, and equipped with three 50-ton tilting furnaces and one 250-ton gas-fired mixer, all of the Wellman type, working in conjunction with blast furnaces.

Some years ago, Mr. John H. Darby[1] at Brymbo demonstrated the value of

[1] "Journal Iron and Steel Institute," 1905, I, p. 122.

the Bertrand-Thiel process in modified form, and introduced an arrangement of plant for conducting the process economically.

Plans of several of the large modern English works with descriptions of their plant, have been given in some of the various trade journals.

The following descriptions and arrangements of typical plants are of works in America and Germany which have been either entirely remodelled or built within the past few years.

American Steelworks

The Gary Plant of the Indiana Steel Co.

The Gary open-hearth plant of the Indiana Steel Co. is perhaps the largest in the world. The works, a very full account of which is given in "The Iron and Coal Trades Review,"[1] are arranged with six independent buildings each equipped with fourteen 60-ton basic open-hearth furnaces, each building being 1189 feet long by 193 feet wide. Fig. 209 shows a section through one of the buildings, and Fig. 210 a part plan. Two 300-ton mixers are erected in each furnace building, and the whole operations of receiving metal from the blast furnaces and distributing same to the open-hearth furnaces proceed in each building independently of the other. They are separate units, and in some respects could be regarded as independent steelworks.

Arrangement of Buildings.—The open-hearth furnace buildings are grouped in pairs, having a large scrap yard with three tracks between each building, in which a skull cracker is erected for breaking heavy scrap and ladle skulls. A mixer building is conveniently arranged at one end of each furnace building, with suitable tracks for receiving the metal from the blast furnaces, and for conveying it from the mixers to the furnaces. The gas producer building runs the full length of the open-hearth furnaces on the side next to the storage lean-to, and special provision is made for receiving the coal on an elevated track and distributing it to each gas producer, after being crushed and elevated to an overhead bunker.

Auxiliary Plant.—A crane of 75 tons lifting power with an auxiliary of 15 tons capacity for tipping the ladle, is used in the mixer-house for handling the hot metal. A 60-ton ladle on electrically-operated hot-metal car is used for conveying the metal to the furnaces. Similar cranes are used over the open-hearth furnace charging floor for pouring the metal from the ladle into the furnace. On the casting side of the furnace cranes of 125 tons capacity, with 25-ton auxiliary cranes, are used for handling the casting ladles.

At the gas producers the coal-handling devices are of the most modern design. Truck-loads of coal are received at the producer building on an elevated railway track. The coal is dropped down a chute from the truck into an electrically-driven coal-crusher, and after being crushed, is elevated to an overhead bunker. From the overhead bunker the coal is distributed to the producers by an automatically-controlled hopper crane which deposits a regulated amount of coal to each producer periodically. In Fig. 187, Chapter XXXI, is shown a somewhat similar arrangement used at the Lackawanna Steel Co.'s Works, but in this arrangement the coal is not crushed before being elevated.

The Union Steel Company's Works, Canton, Ohio.

At the above works an arrangement of modern open-hearth plant designed to compete with larger works has been installed. Six 40-ton basic furnaces are

[1] Vol. 78 (1909), p. 565.

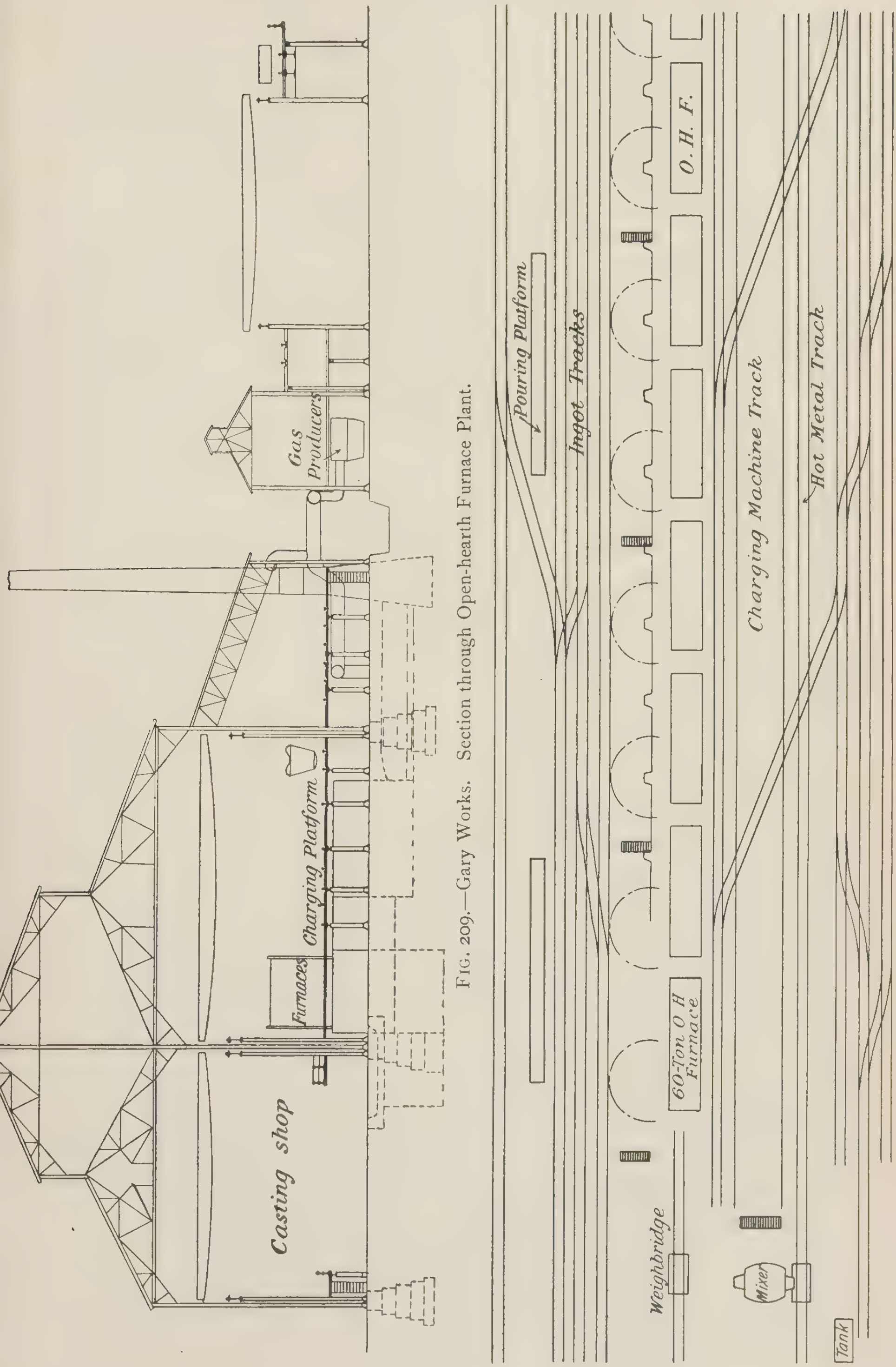


FIG. 209.—Gary Works. Section through Open-hearth Furnace Plant.

arranged in one line, being equipped with charging machine for handling the scrap steel and pig iron, and in the casting shop with overhead cranes.

The gas producers are placed in two lines parallel with the open-hearth furnaces, and coal for their supply is brought over an elevated railway. Pit furnaces adjoin the melting plant for heating ingots for the mill. The cost of producing steel in these works is given in Chapter XXXIII.

German Steel Works

The development and success of the molten metal processes in the open-hearth furnaces have encouraged the construction of new, and reconstruction of old, steelworks in Germany. Two illustrations[1] are given of works started within the last few years, manufacturing steel with molten or semi-molten charges in open-hearth furnaces.

The Georgsmarienhütte.

In Plate VII are illustrated plan and sectional elevations of the steel works of Georgsmarienhütte at Osnabrück, Germany. These works were started in 1907, and are built in close proximity to the blast furnaces, from which the metal is taken in ladle trucks to the mixers. There are five basic open-hearth furnaces, each of 40 tons capacity, erected in line opposite to and parallel with two mixers, one of 150 tons and the other of 250 tons capacity. The furnaces and mixers are connected with the gas producers, which are arranged behind the furnace chimneys and placed parallel with the furnace building. Although the mixers are shown as being connected with the gas producers, the 250-ton mixer is supplied with gas from the blast furnaces and heated entirely by this gas, which is first cleaned and concentrated before reaching the mixer.

Mixers.—The mixers not only collect pig iron from the blast furnace, but refine the metal, so that the work of the open-hearth basic furnaces is greatly reduced; 6 heats are obtained from each furnace every 24 hours.

The blast furnace metal is weighed on a weighbridge outside the building before it is brought to the mixer, after which it is lifted from the truck by an overhead crane of 30 tons capacity and tipped by means of a 5-ton auxiliary crane. The metal is poured into a runner chute mounted upon a frame, and flows into the mixer; a 2-ton charging machine is used for introducing the ore and lime.

The refined metal is poured from the mixer into a ladle suspended from a 60-ton overhead crane. It is weighed on a weighbridge between the two mixers and then brought to the furnace, into which the metal is tipped by the help of a 10-ton auxiliary crane.

Open-hearth Furnaces.—The furnaces are of the ordinary fixed type, arranged with the regenerators below the hearth, and supplied with gas from a battery of producers. Each furnace is connected with a large gas main, through which the gas from all the producers passes. The gas and air valves are operated in the ordinary manner. While the hot metal is charged into the furnace on the same side from which the metal is tapped, a 2-ton charging machine is used on the other side for introducing scrap, ore, and lime, the materials being brought on to the charging stage in pans after being weighed on the weighbridge. An overhead auxiliary runner on mono rail also assists in bringing the materials to the furnaces. The charges are tapped into ladles

[1] By the kind permission of Dr. Petersen and "Stahl und Eisen," Düsseldorf.

suspended from overhead crane and carried to ingot moulds, which are arranged on trucks.

Gas Producers.—At one end of the battery of nine Kerpely rotating producers is a coal storage bunker below the level of the ground. Coal is deposited into this from trucks brought over it, and raised by overhead crane from the storage bunker by means of a collapsible bucket to a 10-ton bunker above the producers and at one side of them. The coal is conveyed to the hopper of each producer by a chute from the overhead bunker. The ashes from the producers are deposited in trucks at one side and below the level of the producers, for easy removal by locomotive.

The Bethlen-Falvahütte.

Another arrangement of German steel works represents one of the latest works built for the production of light ingots of 4 to 5 cwts. each, for the supply of a continuous rolling mill. Solid charges were being melted in the open-hearth furnaces at the Bethlen-Falvahütte until the year 1910, when the new plant illustrated in Plate VIII was installed. The new furnaces and mixer work in conjunction with the blast furnaces in the ordinary way in the supply of liquid iron, but the works are arranged with liberal scrap yard facilities for the supply of 60 per cent. of the total charges as cold scrap. The special feature in this plant is found in the means adopted for the rapid handling of the scrap, which is charged into the furnaces.

From the sectional elevation and plan of the plant it will be observed that between the furnaces and the gas producer plant there is a liberal space for scrap storage, which is spanned by two overhead cranes for handling the scrap. From the main railway two elevated tracks run into the scrap yard. The railway trucks are emptied by electric magnets suspended from the overhead cranes. A press for bundling scrap is placed by the side of each track. The bundles are picked up by an auxiliary runner on the overhead crane and placed in charging pans on the furnace platform within reach of the 2-ton furnace charger. The ease with which each operation is accomplished with the minimum of labour, not only increases the output from the plant, but reduces the operating costs. Table LXXXIV (page 362) gives details of cost of bundling scrap in both hydraulic and electrically operated presses.

General Arrangement of Buildings and Plant.—The general layout of the buildings and plant differs from that of the Georgsmarienhütte. One mixer only is used, of 150 tons capacity, placed in line with and between the furnaces. The methods, however, of charging the molten metal into the furnace and in tapping the charge are the same in both works, and the handling cranes and chargers are similar. The gas producer plant is operated in the same way and with similar coal and ash handling devices as the producer plant at Georgsmarienhütte, although arranged differently on account of the site.

Conclusion.—There are many other interesting features about the detailed arrangements of steel works plant to which reference has not been made, such as the various ways of recording the weights of hot and cold materials, the methods adopted for the storage of the different materials (other than pig iron and scrap) used in the processes, the storage of refractory materials and mills for grinding same, the laboratory for tests, and the lavatory conveniences for the men. These, and other smaller details, are important, and are usually arranged according to convenience. For instance, the storage of refractory materials is frequently arranged for under the charging platform of mixer or furnaces, and the laboratory for tests on the staging or in some central position within easy reach of the furnaces.

TABLE LXXXIV

SCRAP BUNDLING PRESSES

Items of cost.	Kind of Press used.			
	One initial press. Two hydraulic presses. One scrap shears.	Electric press.		
		Pressing direct from wagon.	Scrap moved from yard by hand.	Unloading with magnetic crane for 60-ton output.
1. Average output per shift (tons)	9·25	29·5	26·0	60·0
2. Average weight of bundles (cwts.)	4·5	15·75	15·75	15·75
3. Cost of unloading scrap (shillings)	0·4	0·4	0·4	0·15[1]
4. Power (Cost per shift. Shillings.)	40·25	4·85	4·69	9·07
5. Materials, oils, etc. (Cost per shift. Shillings.)	1·3	0·92	0·92	0·92
6. Repair materials (Cost per shift. Shillings.)	1·56	2·4	2·4	2·4
7. Repairs, labour (Cost per shift. Shillings.)	2·24	0·97	0·97	0·97
8. Air consumed (Cost per shift. Shillings.)	—	1·74	1·56	3·62
9. Wire for bundling (Cost per shift. Shillings.)	4·8	—	—	—
10. Labour (Cost per shift. Shillings.)	21·9	16·56	38·76	19·52
11. Direct cost per ton of pressed bundles	7·8	0·93	1·9	0·61
12. Interest and depreciation per ton of pressed bundles	1·23	0·39	0·44	0·2
13. Total cost of pressed bundles	9·03	1·32	2·34	0·81
14. Cost including unloading	9·43	1·72	2·74	0·96
15. Transport from press to furnace, per ton of bundles	0·66	0·09	0·09	0·09
16. Total cost, including transport to furnace	10·09	1·81	2·83	1·05
17. Cost of charging per ton of bundles	0·54	0·03	0·03	0·03
18. Total cost per ton of bundles	10·63	1·84	2·86	1·08

[1] This includes interest and depreciation.

CHAPTER XXXIII

COST OF STEEL PRODUCED IN TYPICAL LARGE OPEN-HEARTH FURNACES

THE cost of steel production by large open-hearth plants of modern design is now reduced to very fine limits, and depends upon the kind of plant and process employed, and the quality of the product required. The actual cost of the plant is not a serious item when the enormous tonnage produced is considered. Some medium-sized fixed furnace plants, used for melting cold charges in producing ingots of ordinary quality steel for light structural steel sections and similar classes of work, cost little more than 1*s.* for depreciation and interest per ton of ingots produced, when a charge of 15 per cent. is made on the total plant capital. It is understood that the furnaces are kept in operation for about 40 weeks per annum. The question of the continuous operation of a furnace plant has a very marked influence on the final costs of production, not only upon one but many of the items of cost.

The kind of process of steel making conducted in the furnace also influences the final cost. The nature of the process carried out is usually determined by the commercial considerations governing prices of materials and the local demands for the kind of steel products manufactured.

It would be difficult to state costs of production for the various methods employed in furnace plants, without comparing all the operating and purchasing conditions in each case. It is therefore intended to give typical illustrations of costs of steel produced in some plants operated on modern lines and representing the best practice in the three principal steel-producing countries of the world.

COST OF STEEL FURNACE PLANT

The plant included in a modern open-hearth furnace equipment is as follows :—

1. One or more furnaces, complete with regenerators, flues, reversing valves, and separate chimney for each furnace.

2. Gas producers, or batteries of producers, arranged in pairs or in groups of three, according to their size and the size of the furnace to be supplied. Also flues connecting producers and furnaces.

3. All the coal handling and other apparatus and equipment required for the supply of fuel to the producers, and the removal of ashes.

4. Cranes and charging machines, locomotive and trucks, charging boxes, railway track, weighbridges, ladles, and all the necessary plant for handling the raw materials to and from the stock yard, and at the furnaces in taking the steel to the casting floor.

5. Generating plant, if power for operating electrically cannot be purchased

at a reasonable price from an outside supply, or from the power department which exists in the steelworks where it is proposed to instal new plant. Such generating plant to include steam boilers for gas producers, pumps, etc., for water power, and apparatus for lighting throughout.

6. Buildings.

7. All foundations for plant and buildings.

Cost of Furnaces.—Considering only the cost of furnaces, there are on record estimates and costs of furnaces actually designed, and others which have been verified by having been constructed and put into operation. The following details are taken from the sources named, and can be compared with the prices paid by manufacturers for furnaces of similar design which may be in operation in their own works.

Details of Cost of Two 50-Ton Furnaces[1]

The following costs were prepared by Mr. F. H. Treat, consulting engineer, Pittsburg :—

One furnace, complete with 66 feet length of buildings, stock yard, producers, buildings, etc.—

	£	s.	d.	£	s.	d.
Iron and steel work for one 50-ton o.h. furnace—						
Charging floor, 89,000 lbs. @ $1\frac{7}{8}d.$	695	6	0			
Track rails, 13,200 lbs. @ 1*d.*	55	10	0			
Beams and channels for furnace binders, 100,000 lbs. @ $1\frac{1}{2}d.$	625	0	0			
Steel castings, 51,000 @ $2\frac{1}{2}d.$	531	5	0			
Stack, 40,000 lbs. @ 2*d.*	333	6	0			
Reversing valves and dampers, gas box, and flue connections, and regulating apparatus	625	0	0			
				2,865	7	0
Brickwork and lining for one 50-ton o.h. furnace :						
Furnace and regenerators—						
220,000 common bricks @ 62*s.* 6*d.*	687	10	0			
65,000 silica bricks @ 145*s.* 10*d.*	473	19	0			
235,000 No. 1 clay bricks @ 125*s.*	1468	15	0			
10,000 magnesite bricks @ 770*s.* 10*d.*	385	8	0			
				3,015	12	0
Flues—						
30,000 No. 2 clay bricks @ 104*s.* 2*d.*	156	5	0			
30,000 common bricks @ 62*s.* 6*d.*	93	15	0			
				250	0	0
Stack—						
40,000 No. 2 clay bricks @ 104*s.* 2*d.*	208	6	0			
90,000 common foundation bricks @ 62*s.* 6*d.*	281	5	0			
				489	11	0
50 tons magnesite @ 83*s.* 4*d.*	208	6	0			
450 tons coal	375	0	0			
Labour making bottom	72	18	0			
Concrete, 3500 cubic feet @ 10*d.*	145	16	0			
				802	0	0
Total cost of furnace				£7,422	10	0

[1] "Iron Age," vol. 71, p. 30.

	£ s. d.	£ s. d.
Producers and equipment—		
5 producers @ £229 3s.	1145 15 0	
5 gas flue connections	104 3 0	
Building 16′ × 66′	318 6 0	
Coal handling machinery	208 6 0	
Main gas flue	260 8 0	
		2,036 18 0
Building 66 feet in length. Furnace, charging, and casting shops—		
195,000 lbs. steel and iron work @ $1\frac{7}{8}d.$ . .	1502 10 0	
Foundations	256 5 0	
Narrow gauge tracks	68 15 0	
Excavation, 3020 cubic yards @ 1s. 3d. . .	188 15 0	
		2,016 5 0
Stock yard, including runways for crane and railway tracks	307 18 0	
7 mould cars @ £62 10s.	437 10 0	
1 steel ladle	312 9 0	
24 charging boxes	375 0 0	
6 cars for charging boxes	312 10 0	
1 cinder car	62 10 0	
		1,807 17 0
Total cost for one furnace . . .		£13,283 10 0
Total cost for two furnaces . . .		£26,567 0 0

The foregoing details are given in full, as they set forth in a comprehensive manner a schedule of the materials required in building a 50-ton furnace plant and producers.

The following table gives a summary of the costs of a few different sizes of furnaces with necessary producers :—

TABLE LXXXV

COSTS OF FURNACES AND PRODUCERS

	Size of furnace.	Gas producers.	Cost.	Remarks.
			£	
1	One 50-ton furnace		7422	Two furnaces and 10 producers included in the scheme.[1]
		5 gas producers	2036	
2	One 40-ton ,,		4625	Three furnaces included in the arrangement. Eleven producers used for three 40-ton furnaces and one pit furnace. Total cost of producers £4458.
		3 ,, ,,	1215	
3	One 30-ton ,,		8309	Three furnaces with chimney, platform, and casting pit in scheme. Eight producers supplying the 3 furnaces.
		$\frac{1}{3}$ of 8 gas producers	3316	
4	One 20-ton ,,	With producer	5208	Six 20-ton furnaces with producers included in the scheme.

1. "Iron Age," vol. 71, p. 30.
2. "Iron Trade Review," Oct. 27th, 1904, p. 32.
3. "Iron and Coal Trades Review," 1910, p. 367.
4. "Iron Age," vol. 47, p. 1108.

In the remarks column of the above table, the notes explain the size of the complete plant of which the itmes named form a part. In the case of the 40-ton furnace, the cost does not include foundations, which appear as a separate item in the complete cost of the equipment of the furnace and plant. The following summaries give details of the 50, 40, 30, and 20-ton plants referred to in Table LXXXV :—

50-*Ton Open-hearth Furnace Plant.*

	£	s.	d.
Two 50-ton furnaces and 10 producers, complete with buildings, stockyard, etc	26,567	0	0
One 75-ton ladle crane	4,560	8	0
" " freight and erection	270	17	0
One stock crane	807	6	0
" " freight and erection	41	13	0
One charging machine	2,187	10	0
" " freight and erection	104	3	0
Two extra ladles	625	0	0
Ladle repair stand	62	10	0
Casting stand and car mover	250	0	0
Coal hopper, crusher, and elevator	416	13	0
Ends and extra bay in main building, including foundations and excavation	1,545	12	0
One electric stripping crane	3,020	17	0
" " " freight and erection	175	0	0
120-ft. runway for above	300	0	0
One 20-ton narrow-gauge locomotive	833	6	0
Westinghouse 200 k.w. generator	786	9	0
Engine for above	701	9	0
" " freight and erection	104	3	0
Grand total	43,359	16	0
Engineering and incidentals, 10%	4,337	4	0
Total for 2-furnace plant	£47,697	0	0

40-*Ton Open-hearth Furnace Plant.*

	£	s.	d.
Buildings for furnace and mill	14,645	16	0
Foundations and grading	8,250	0	0
One pit furnace	2,750	0	0
Three open-hearth furnaces	13,875	0	0
Eleven gas producers and plant	4,458	6	0
Cranes, charging machine, etc.	9,395	16	0
One 48″ Universal mill	12,208	6	0
Auxiliary table and shears	10,000	0	0
Boilers	4,895	17	0
Engines, pumps, and dynamos	8,979	3	0
Steam fittings, wiring, and lighting	5,666	13	0
Scales, buggies, track, etc.	3,833	6	0
Total	£98,958	3	0

The above cost includes buildings for mill, rolling mill, and mill machinery, but as part of the auxiliary plant for the mill is used for the steel plant, the items have not been separated, but given as shown.

30-*Ton Open-hearth Furnace Plant.*

	£
Steelworks building	7,350
Three 30-ton O.H. furnaces, with chimney, platform, and casting pit	24,927
Mixer	12,700
Charging apparatus	1,450
Four cranes	3,950
Three 30-ton ladles	1,050
Wagons, etc.	1,290
Eight producers, with gas mains and buildings	9,950
Sundries	2,218
Total	£64,885

20-*Ton Open-hearth Furnace Plant.*

	£	s.	d.
Six 20-ton furnaces, with producers, platforms, etc.	31,250	0	0
Two cranes on trucks for steel ladles	2,083	6	0
Locomotive for above	833	6	0
Three hydraulic hoists	624	7	0
Casting pit	416	13	0
Four Wellman cranes	1,457	13	0
Twelve steel ladles	1,250	0	0
Twelve ingot trucks, twelve mould trucks	1,041	13	0
One hundred ingot moulds	2,707	13	0
Hydraulic plant	1,666	12	0
Four boilers, 100-h.p. each	1,041	13	0
Buildings, 350′ × 120′ × 40′	8,750	0	0
Tracks, steam hammer, etc.	624	7	0
Total	£53,747	3	0
Unprovided for	5,416	14	0
Engineering, etc.	5,416	14	0
Grand total	£64,580	11	0

The above cost is rather old, and is therefore subject to modification. This should be borne in mind when comparing it with other costs.

Working Costs of Large Open-hearth Furnaces.—In the costs of plants given, only one includes a mixer. The use of a mixer is generally adopted in all large plants where molten charges are used, and are commonly employed when the pig iron is made within reasonable distance of the steel plant. The use of molten metal decreases the working costs, the duration of the heat is shortened, and fuel is saved in melting.

75-Ton Basic Open-hearth Furnace Plant

We give the following costs for the production of basic steel from furnaces of the above capacity.

Output.—The total output per week is taken at 5000 tons, or equal to about 2 to $2\frac{1}{2}$ heats per furnace per 24 hours. The furnaces are kept in continuous operation.

Size and Cost of Plant required.—Five open-hearth furnaces are employed. The repairs to the five furnaces are almost equivalent to one furnace being constantly idle. The furnaces are nominally of 75 tons capacity, and are worked with half liquid iron and half steel scrap charges. Each furnace is supplied with gas from a group of 3 producers, each capable of gasifying 24 tons of coal per day.

The groups of producers can be coupled together if desired, so that if one group is out for repair another can be put in operation. The other items of plant include :—

One 500-ton mixer.
One overhead furnace crane of 75 tons capacity.
Two charging machines.
One overhead gantry crane in scrap yard.
One locomotive with trucks, charging boxes, etc.
Two 125-ton casting cranes with 30-ton auxiliary crabs.
Two charging ladles and ladle chutes for furnaces.
Three casting ladles.
Two physic ladles, weighbridges, tables, etc.

The approximate cost of the plant, complete with foundations, buildings, and all necessary power equipment is £200,000.

Depreciation and Interest on Plant.—Taking 15 per cent. on plant outlay to cover depreciation and interest, the charge per annum = 15 per cent. of £200,000 = £30,000.

∴ Charge for depreciation and interest per ton of steel

$$= \frac{30,000 \times 20}{240,000} = 2s.\ 6d.$$

240,000 tons is the annual output recorded on the five furnaces, being employed continuously except when shut down for repairs.

Repairs.—These include materials for the repair of mixers, gas producers, furnaces, ladles, etc., and the approximate cost per ton of steel = 2*s*. 9*d*. for materials only.

Fuel.—Taking coal at 10*s*. per ton and the total consumption per ton of steel at 600 lbs., which is a fair average for large furnaces working with partly molten steel charges, the cost per ton of steel = 2*s*. 8*d*. Additional fuel for heating furnaces, mixers and ladles (coal and oil fuel) = 9*d*. per ton of liquid steel.

Labour.—Including the chemists, melters, first and second hands, helpers, gas producer men, ash handling men, loco men bringing liquid metal to mixer, mixer men, weighbridge men, crane men, charging machine hands, ladle men, pourers, stock yard labourers, slag truck men, and the repairing gangs and helpers, the labour cost per ton of steel = 3*s*. 9*d*. approximately.

Raw Materials.—Taking the cost of the pig iron delivered at the mixer to be 50*s*. per ton and the furnace scrap at 45*s*. per ton, the cost of liquid steel is as follows :—

To produce 5000 tons of liquid steel per week, 5350 tons of material are required, divided in the proportion of—

	£	s.	d.
2675 tons of pig iron @ 50s.	6,687	10	0
2675 ,, scrap ,, 45s.	6,018	15	0
Total cost of raw materials per week . .	£12,706	5	0

$$\therefore \text{ Cost of materials per ton of liquid steel} = \frac{£12{,}706\ 5s.}{5000} = 50s.\ 10d.$$

Cost of Fluxes: This varies in amount according to the kind of materials employed in the charge and the prices per ton of limestone, lime, and fluorspar, which fluctuate and vary in different countries. An average cost per ton of steel is taken at 1*s.*

Cost of Ferro Additions: For recarburising when making ingot steel for rails, it is usual to take sufficient iron from the mixer and pour the metal into the casting ladle as the steel is being tapped from the furnace to bring the carbon in the charge up to the desired limit. In the case of furnaces of the capacity now being considered, the weight of pig iron required is considerable, and increases the tonnage of steel produced.

As each ton of mixer metal added to the casting ladle makes one ton extra of liquid steel, the cost of steel production is less by making additions in this manner than when using a smaller amount of pig iron and proportionately more spiegeleisen, ferro-manganese, and ferro-silicon.

Ferro-manganese and Ferro-silicon: These additions combined average, for mild ingot steel, about 20 lbs. per ton, or an approximate cost per ton of liquid steel of 1*s.* 6*d.*

General and office expenses (share) are taken at approximately 1*s.* 6*d.* per ton.

Summary of Costs

Per ton of steel for ingots from five 75-ton open-hearth furnaces producing 5000 tons of liquid steel per week.

Cost of plant, £200,000.

	£	s.	d.
Depreciation and interest	0	2	6
Repairs (materials only)	0	2	9
Fuel	0	3	5
Labour	0	3	9
Raw materials and additions	2	10	10
,, ,, fluxes	0	1	0
,, ,, ferro-manganese, ferro-silicon, and aluminium	0	1	6
General and office expenses (share)	0	1	6
Cost per ton of liquid steel . .	£3	7	3

If scrap is taken at 50*s.* per ton, the cost of steel is £3 9*s.* 11*d.* per ton.

40-Ton Basic Open-hearth Furnace Plant

Cost of Steel Production

From the details of a plant designed and installed by Mr. Victor Beutner at the United Steel Company's Works at Canton, Ohio, the following particulars of output and costs have been prepared from details given by him.[1] They are set forth in the following order for comparison with other costs.

[1] "Iron Trade Review," October 27th, 1904, p. xxv.

Output of Plant.—The plant (enumerated on page 366) consists of 3 open-hearth furnaces, each of 40 tons capacity, producing 40 heats per week, melting 1600 tons of material and producing 1472 tons of ingots weekly.

Cost of Plant.—The total capital expenditure on plant and mill was £98,957, and assuming that the total approximate cost of three furnaces and complete equipment of the auxiliary plant to be £50,000, which would be a fair approximation, the annual charge for depreciation and interest is as follows:—

	£
Depreciation, 10% of £50,000	5000
Interest, 5% of £50,000	2500
Charge for depreciation and interest per annum . .	£7500

Assuming 40 working weeks per year, *i.e.* an annual output of 1472 × 40 = 58,880 tons of steel, the charge for depreciation and interest per ton

$$= \frac{7500 \times 20}{58,880} = 2s.\ 6d. \text{ approx.}$$

Working Costs per Ton of Ingots

Repairs.—The materials used in repairing the furnaces, ladles, etc., per week's campaign are as follows:—

	£	s.	d.
15 tons of magnesite @ 87*s.* 6*d.* per ton	65	12	6
25 „ dolomite @ 14*s.* 7*d.* „	18	4	7
Clay, bricks, nozzles, etc	25	0	0
Total . .	£108	17	1

$$\therefore \text{ Cost per ton of ingots} = \frac{£108\ 17s.\ 1d.}{1472} = 1s.\ 6d. \text{ approx.}$$

Fuel.—Eleven gas producers of the Swindell type are used, each capable of gasifying 10 tons of good coal per 24 hours. They supply the pit furnace in addition to the open-hearth furnaces, but the coal consumed at the open-hearth furnaces is recorded at 680 tons per week.

680 tons of gas coal @ 9*s.* 2*d.* per ton = £311 13*s.*

$$\therefore \text{ Cost of fuel per ton of ingots} = \frac{£311\ 13s.}{1472} = 4s.\ 3d.$$

Labour.—The list of men employed on both shifts per week, and their duties and wages are as follows:—

	per day. s.	d.	per week. £	s.	d.
2 melters . . . . @	22	11	13	15	0
6 first helpers . . . . . „	11	5½	21	15	0
12 second helpers . . . „	6	10½	24	15	0
2 steel pourers . . . . . „	12	6	7	10	0
6 pitmen . . . . „	7	3½	13	2	6
2 cranemen . . . . „	12	6	7	10	0
2 charging-machine men . „	9	4½	5	12	6
1 ladle man . . . . „	8	4	2	10	0
2 gas makers . . . . . . „	10	5	6	5	0
4 helpers . . . . „	6	10½	8	2	6
20 labourers . . . . „	5	7½	33	15	0
2 chemists			8	6	8
Total . .			£152	19	2

The cost of labour, therefore, per ton of ingots

$$= \frac{£152\ 19s.\ 2d.}{1472} = \text{approx. } 2s.\ 1d.$$

Raw Materials.—The following weights of raw materials are used per week:—

	£	s.	d.
640 tons of pig iron @ 50s. per ton	1600	0	0
916 „ scrap @ 41s. 8d. „	1908	7	0
12 „ ferro-manganese @ £10 16s. 8d. per ton	130	0	0
64 „ ore (50% Fe) @ 18s. 9d. per ton	60	0	0
Total	£3698	7	0

$$\therefore \text{ Cost of materials per ton of ingots} = \frac{£3698\ 7s. \times 20}{1472} = 50s. \text{ approx.}$$

Fluxes:

	£	s.	d.
144 tons of limestone @ 2s. 6d. per ton	18	0	0
8 „ fluorspar @ 41s. 8d. „	16	13	4
Total	£34	13	4

$$\therefore \text{ Cost of fluxes per ton of ingots} = \frac{£34\ 13s.\ 4d.}{1472} = 6d. \text{ approx.}$$

General Operating Expenses.—The total general operating expenses such as fuel for boilers, oil, etc., and labour such as firemen, electrician, loco engine men, millwright, blacksmith, bricklayers, weighbridge clerks, and helpers is equal to £276 1s. 0d. per week for the whole works. Taking $\frac{1}{3}$ of this amount for the steel plant and the remaining $\frac{2}{3}$ to the mill, the cost per ton of ingots

$$= \frac{1}{3} \times \frac{£276\ 1s.\ 0d. \times 20}{1472} = 1s.\ 3d.$$

Office and Selling Expenses.—The total weekly office and selling expenses is given as £62 10s. 0d. If the steel plant bear $\frac{1}{2}$ the cost *i.e.* £31 5s. 0d., the cost per ton of ingots $= \frac{£31\ 5s.\ 0d. \times 20}{1472} = 5d.$

Summary of Costs

Per ton of ingots from three 40-ton open-hearth basic furnaces producing 1472 tons per week.

Cost of plant, £50,000.

	£	s.	d.
Depreciation and interest	0	2	6
Repairs (materials only)	0	1	6
Fuel	0	4	3
Labour	0	2	1
Raw materials (metals)	2	10	0
„ „ (fluxes)	0	0	6
General operating expenses including power (share)	0	1	3
Office and selling expenses (share)	0	0	5
Cost per ton of ingots	£3	2	6

Total metals charged	1600 tons
Ingots produced	1472 ,,
Loss and waste	8 per cent.

If the price of pig iron is taken at 60*s.* per ton and the scrap at 45*s.* per ton, the price per ton of ingots is increased as follows :—

640 tons of pig iron @ 60*s.*	£1920
916 ,, scrap @ 45*s.*	2061
Total	£3981

$\therefore \frac{3981 \times 20}{1472}$ = 54*s.* 1*d.* per ton of ingots, or an increase of 4*s.* 1*d.* over cost already given, ∴ cost per ton of ingots = £3 6*s.* 7*d.*

If the price of pig iron and scrap be taken at 65*s.* and 50*s.* respectively, the price per ton of ingots will be—

640 tons of pig iron @ 65*s.*	£2080
916 ,, scrap @ 50*s.*	2290
Total	£4370

$\therefore \frac{4370 \times 20}{1472}$ = 59*s.* 5*d.* per ton of ingots, or an increase of 9*s.* 5*d.* per ton on the original cost, making the cost = £3 11*s.* 11*d.* per ton.

35-Ton Basic Open-hearth Furnace Plant

Rapid Melting. Solid Charges

The following is a typical modern steel furnace plant used in a rolling mill steel works in Germany producing light mild steel sections for structural work, light rails, and other classes of work.

Output of Plant.—The output per week of each furnace, working from Sunday night to Sunday morning = 1050 tons of ingots, and calculating the cost on the production of two furnaces, the weekly output is 2100 tons of ingots. The materials are charged into the furnace in the solid state.

Cost of Plant.—The following plant is required for the above production, and by the kindness of the designers of the furnaces and producers, Messrs. Paul Schmidt and Desgraz, we had the opportunity of witnessing its operation in Germany.

Buildings and structural work for furnaces and producers.
Two 35-ton basic open-hearth furnaces.
Two gas producers (Goliath type) each to gasify 30 tons of rough coal per 24 hours.
Cranes and charging machine.
Locomotive, trucks, pans, etc.
Boilers, pumps, etc.
Weighbridges and ladles.
Foundations, track, etc.

The total approximate cost of the above equipment is £40,000.[1]

Depreciation and Interest.—Allowing a charge of 10 per cent. of the total

[1] This figure is estimated.

plant cost for depreciation, and 5 per cent. for interest, the annual charge is as follows :—

£40,000 @ 10%	. . . . . .	£4,000
£40,000 @ 5%	. . . . . .	2,000
	Total	£6,000

Taking 40 working weeks per year, the annual output of ingots = 2100 × 40 = 84,000 tons.

∴ Charge for depreciation and interest per ton of ingots

$$= \frac{6000 \times 20}{84,000} = 1s.\ 5d. \text{ approx.}$$

Working Costs per Ton of Ingots

Repairs.—The furnaces have specially long ports, and are designed with a view to the reduction of repair costs, which are rather less than in ordinary furnaces of the same size operated on the principle of melting and converting without refining the charge. About 350 charges are made from each furnace without stopping (excepting the short interval on Sundays). The approximate cost of repairs per ton of ingots = 2*s.*

Fuel.—The cost of fuel is an important feature in this plant, as one producer only is used with each furnace. The producer is of the revolving grate type, and consumes about 4¼ cwts. of good gasifying coal per ton of ingots produced. Taking the price of coal at 10*s.* per ton, the cost of fuel per ton of ingots = 2*s.* 1½*d.* approx.—an exceedingly low figure. Other fuels for heating ladles, ferro-manganese, etc. = 4*d.* per ton.

Labour.—The materials are taken from the stock yard adjoining the furnace in charging machine boxes on the usual form of truck. From the huge stacks of scrap steel the boxes are filled by an electric magnet suspended from an electric crane. The labour involved in filling the boxes is reduced to a minimum, but takes rather longer than the ordinary box filling with the same appliances because an assortment of scrap and pig is made in order to produce the quality of steel required without refining the charge. The men employed are as follows :—

Two melters.
Four first hands.
Six second hands.
Two charging machine hands.
Eight casting pit men.
Two ladle pourers.
Two crane men.
Two gas producer men.
Two helpers.
Two crane men at producer plant.
Fifteen labourers.
Two chemists.

The total estimated cost of labour is £130 per week for the two shifts.

$$\therefore \text{Cost of labour per ton of ingots} = \frac{130 \times 20}{2100} = 1s.\ 3d.$$

Labour on repairs to furnaces, ladles, cranes, and other equipment = approx. 1*s.* per ton.

∴ Total cost of labour = 2*s.* 3*d.* per ton

Materials used.—The furnace charge consists of the following materials:—

Pig iron (miscellaneous brands)	5	tons
Ingot mould scrap	$1\frac{1}{2}$	,,
Rolling mill scrap (joists, channels, bars, billets, etc.)	18	,,
Iron turnings	3	,,
Light scrap steel (miscellaneous sheet steel and iron chippings, tubes, forgings, etc.)	$8\frac{1}{2}$	,,
Total	36	tons

To produce 2100 tons of ingots per week each furnace melts 32 charges weekly, or an equivalent of one charge every $4\frac{3}{4}$ to 5 hours.

The two furnaces use the following materials:—

Pig iron	5 tons	× 64 =	320 tons
Scrap	31 ,,	× 64 =	1984 ,,
		Total	2304 tons

	£
Cost of pig iron, 320 tons @ 50*s.*	800
,, scrap, 1984 tons @ 45*s.*	4464
Total	£5264

Cost per ton of ingots $= \frac{5264 \times 20}{2100} =$ 50*s.* 2*d.* approx.

Fluxes: Average cost per ton = 4*d.* approx.

Ferro-manganese and ferro-silicon: These additions vary, but average about 1*s.* 6*d.* per ton of ingots.

Fixed charges for management: These can only be estimated approximately, but 1*s.* 6*d.* per ton of ingots would liberally cover these charges.

Summary of Costs

Per ton of ingots made by two 35-ton basic open-hearth furnaces producing 2100 tons of ingots per week of 156 hours.

Cost of plant, £40,000.

	£	*s.*	*d.*
Depreciation and interest	0	1	5
Repairs (materials only)	0	2	0
Fuel	0	2	$5\frac{1}{2}$
Labour	0	2	3
Raw materials (pig iron and scrap)	2	10	2
,, ,, (fluxes)	0	0	4
,, ,, (ferro-manganese and ferro-silicon)	0	1	6
Fixed charges for management, including power and lighting (share)	0	1	6
Cost per ton of ingots	£3	1	$7\frac{1}{2}$

Acid Open-hearth Furnace Costs.—The foregoing illustrations of costs are from basic open-hearth practice, and could be multiplied considerably because of the variety of methods employed in both open-hearth fixed and tilting furnaces. In comparing the cost of acid open-hearth steel produced from the

same size of furnace under similar conditions, excepting in the kind of furnace lining and materials forming the charge, it is found that the total costs per ton do not differ much. As a rule, basic pig iron for the open-hearth furnace can be purchased at a lower price than pig iron for the acid process; on the other hand, the fluxes used in the basic process cost more than those used in the acid process.

Comparing the costs of both processes as conducted in Germany, G. Bergstrom [1] gives the following costs per ton of ingots produced :—

	Basic Open-hearth			Acid Open-hearth		
	£	s.	d.	£	s.	d.
Pig iron, etc.	2	13	0	2	15	0
Labour	0	5	0	0	5	0
Coal and sundries	0	10	0	0	11	0
Total	£3	8	0	£3	11	0

[1] "Journal Iron and Steel Institute," 1895, II, p. 508.

CHAPTER XXXIV

STEEL PRODUCTION IN SMALL OPEN-HEARTH FURNACES

THE term "small" is used here in a comparative sense, to distinguish the costs given for ingot steel production in large open-hearth furnaces from the costs for steel employed for steel castings. The range of weight of steel castings made from steel manufactured in the open-hearth furnace is so extensive that it would be impracticable to attempt to produce steel suitable for all classes of castings from one standard size of furnace. For instance, some steel castings used in motor manufacture weigh only a few ounces, while others used for the stern frames of the largest steamships weigh nearly 100 tons. Furnaces of different capacities are therefore built to meet the varied requirements. Open-hearth furnaces of less than 2 tons capacity have not found favour in this country. In America, small furnaces of ½-ton capacity have been put into successful operation.

Open-hearth furnace plants for steel foundries may be conveniently divided into three sections :—

1. Furnaces below 5 tons capacity.
2. Furnaces between 5 and 20 tons capacity.
3. Furnaces over 20 tons capacity.

1. **Open-hearth Furnace Plants below 5 Tons Capacity.**—Many old-fashioned Siemens Furnaces, from 5 tons capacity downwards, are still used in steel foundries for dealing with castings for general use, such as colliery, mining, railway, etc. It is difficult to produce castings with sections less than ¼ inch thick from steel made in such furnaces, hence the retention of the crucible process and the small side-blown Bessemer converter, in which higher temperatures are obtained, and therefore greater fluidity of steel.

2 TO 3-TON "NEW FORM" SIEMENS FURNACE

Probably the most useful size of open-hearth furnace for the small miscellaneous steel foundry producing about 25 tons of liquid steel weekly, is one of 2 to 3 tons capacity. From such a furnace, steel for castings up to 2 tons weight each could be produced, although it is not usual to have auxiliary plant suitable for handling such weights where an output of 25 tons per week is the limit. In some small foundries where steel castings of one or two classes only are manufactured, such as mining and colliery wheels, no overhead cranes are employed, and the chief cost of the foundry is in the furnace and buildings.

In one foundry in Westphalia, Germany, near to the colliery town of Hagan, we had the opportunity of witnessing the rapid production of steel castings direct from a 3-ton Siemens furnace. The metal was tapped into shanks of about 2 cwts. each, and carried direct to the moulds on the floor near by. After 3 or 4 shanks had been filled, one of which was kept below to catch the stream

of metal between the filling of consecutive shanks, the tap hole was closed in the same manner as a cupola is "bodded up." The hole was opened and closed repeatedly during the emptying of the furnace. This practice is not, of course, confined to Germany, as for many years at the works of the Darlington Forge tapping and closing was performed in this way. Where this is done skilfully, and a running tap hole is avoided, the temperature of the steel taken from the furnace in this manner suffers less loss of heat than when transferred from one ladle to another before reaching the mould. The initial cost of plant and the maintenance cost of the foundry are also less.

The following is a description of the "New-Form" Siemens furnace as used in steel foundries.

General Description.—For melting steel rapidly, the small "New-Form" Siemens furnace is better adapted than the ordinary Siemens furnace. This

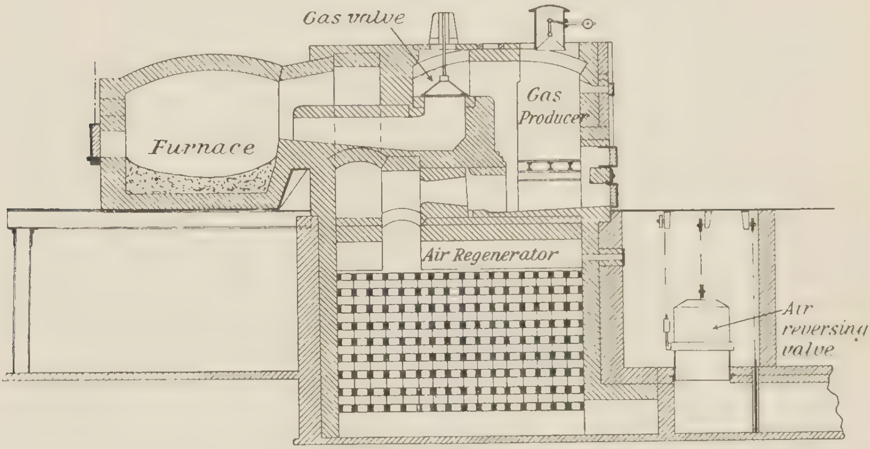


FIG. 211.—Siemens' "New-Form" Furnace.

furnace differs from the old form of Siemens furnace in several respects, and the general arrangement is different, as will be observed by comparing Fig. 149 on page 289 with Fig. 211, showing plan and elevation of the furnace now being described. The main features are as follows:—

(*a*) The melting hearth, gas producer, and regenerators are built together, forming one structure. The regenerators consist of two chambers of chequer-work (built under the gas producer), through which air passes for combustion with the gas from the producer. The gas coming direct from the producer into the furnace is sufficiently high in temperature to combine with the air, and needs no regenerators. There are, therefore, two air regenerators only. The waste gases from the melting hearth expend most of their heat upon the chequer brickwork in passing through the regenerators on their way to the chimney. Each regenerator in turn is heated by the hot gases, and cooled by the air passing into the furnace. This process of heating and cooling proceeds throughout the operation of the furnace.

(*b*) The arrangement of the gas and air ports differs from the ordinary furnace. Instead of the gas and air passing into the furnace at one end and out at the other, they enter and pass out at the same end, after making a journey round the furnace hearth. There are two gas and two air ports side by side on the producer side of the furnace hearth. When one gas port is open

from the producer to the furnace, the other is shut. The air port to the furnace on the side through which gas is passing is open to the atmosphere, the air from which is drawn through the reversing valve to the combustion chamber. At the same time, the valve opens the exit to the chimney to allow the spent gases passing through the opposite regenerator to escape.

The admission of gas from the producer to the furnace is controlled by two valves, one being open while the other is closed. The natural draught from the chimney not being sufficient to draw the gas into the furnace and give a satisfactory result, steam pressure is applied to the producer, the steam passing through the fuel in the ordinary way. With a steam pressure of about 50 lbs. per square inch, a very good flow of flame is obtained round the hearth of the furnace.

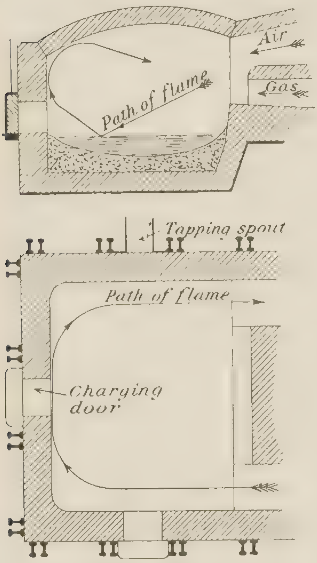


FIG. 212.—Hearth of "New-Form" Siemens Furnace.

Fig. 212 shows a larger view of the furnace hearth, which is made up of brickwork and has a sand bottom. The charging door is at the end opposite the port holes, and suffers rather severely from the cutting action of the flame. There is another door on one side opposite to the tap hole—this is very useful for the inspection of the hearth and for other purposes.

Operation of the Furnace.—When the furnace and producer are built, the brickwork is allowed to dry naturally for a day or two before any fire is introduced. It is important that the furnace be heated very slowly with a wood and coal fire, and gradually brought up to a white heat before a charge is introduced. The furnace, as a rule, is worked continuously; that is, heats are taken from it day and night, two complete gangs of men operating. In small foundries, however, where the men are employed on day shift only, two or three heats are obtained during the 12 hours, according to the quality of steel required. When making steel with about 75 per cent. scrap and 25 per cent. pig, about 4 to 5 hours are required to melt three tons, and finishing takes about $1\frac{1}{2}$ to 2 hours more. The charging of the first heat being commenced on Monday morning soon after midnight, it is ready about 8 to 8.30 a.m. At 9 a.m. the second heat is charged, and tapped about 4 p.m. Thus, where castings for ordinary engineering purposes are required, two heats per day are all that can be obtained from this furnace. Where the charge requires to be melted only, and is not brought up or down in carbon by additions of pig or ore, three heats are possible during the working day. After the heat referred to above is tapped in the afternoon, the furnace is not again charged until after midnight, when the same procedure takes place as on the Monday. This is continued until Saturday morning, when the eleventh heat for the week is tapped. During the week-end the gas producer is kept going all the time, maintaining the furnace at a reduced temperature.

Output and Cost of Furnace.—A furnace with a capacity of 2 to 3 tons will produce 25 tons of liquid steel per week, working day shift only. The cost of a "New-Form" furnace to produce from 2 to 3 tons per heat is considerably less than that of an ordinary Siemens furnace of the same capacity. Considering that two regenerators only are required instead of four, and that the gas producer forms part of the furnace structure, less brickwork is required, less space is occupied, and the initial cost of installing is thereby reduced from 30 to

50 per cent. of that of the older form of furnace, according to the conditions of the site. The furnace alone, excluding foundations, chimney, boiler, and royalties, costs from £650 to £750, but before one could be set in operation, where it is necessary to instal chimney and boiler, the cost would be from £1500 to £2000.

Assuming the price to be £1800, and allowing for an annual depreciation of 10 per cent. on plant, and 5 per cent. interest on capital, the annual charge for these two items = 15 per cent. of £1800 = £270.

Taking an output of 25 tons of steel per week for 48 weeks per year, the annual output of steel in ladle = 25 × 48 = 1200 tons.

∴ Charge for depreciation and interest per ton of liquid steel

$$= \frac{270 \times 20}{1200} = 4s.\ 6d.$$

Working Costs (per Ton of Liquid Steel for Carbon Steel Castings)

Cost of Repairs.—In the "New-Form" Siemens the cost of repairs is much less than in the ordinary Siemens furnace. The fact that two regenerators only are required, and that they are placed away from the hearth of the furnace, thereby removing the possibility of slag and steel getting into them should a leak or an accident arise, are factors which tell in the reduction of the repair costs. The hearth of the furnace is, of course, subject to the same wear as the ordinary hearth, but the ports are not. The latter often last much longer than the roof and door jambs. The cutting action of the flame in sweeping round the furnace is felt, perhaps, more on the brickwork around the charging door and on the roof near the door, than elsewhere. When driving the melt by using a high pressure of steam in the gas producer, the intensity of the flame is considerable at these parts. In Fig. 212 is shown the path of the flame. On entering the furnace from the gas producer it strikes the surface of the metal, and is directed upwards in the direction of the arrow on to the crown of the furnace whilst surging round the doorway. The result is that the doorway soon wears, and a loss of heat takes place around the door. The crown also suffers. These parts require to be repaired rather more frequently than any other parts of the furnace.

Advantage is taken of the three principal holidays in the year for overhauling and making good the furnace. The bottom of the furnace requires burning down and remaking frequently, sometimes once every month. At other times it may be two months before this is necessary, according to the working of the furnace and the materials being melted. This remaking of the bottom is done at the week-end, after the last heat is tapped on Saturday morning and before the first charge is put in on Monday morning. Repairs are also necessary occasionally to the producer and its fittings, and to the boiler. There is also the maintenance of tools for working the furnace. The total cost of entire repairs and maintenance is approximately £350 per annum. The cost of repairs, therefore, per ton of steel melted

$$= \frac{350 \times 20}{1200} = 5s.\ 10d.$$

Cost of Fuel.—The coal found most serviceable and economical in this furnace is the common non-caking slack or nuts, which can be purchased at from 8*s*. to 10*s*. per ton. The percentage of ash may vary from 5 to 10 per cent., but the lower it is the higher is the heating value obtained from the fuel, and less labour is entailed in cleaning the producer. The average weight of coal consumed per ton of steel melted during one week's run is approximately 12 cwts.

This includes the fuel required to keep the furnace alight during the nights and week-end.

Taking the price of coal at 9*s.* per ton, the cost of fuel required to generate gas per ton of steel melted is approximately 5*s.* 5*d.* The cost of fuel used at the boiler in generating steam for the producer is approximately 2*s.* 7*d.* per ton of steel. The total cost for fuel is therefore 8*s.* per ton of steel in the ladle.

Cost of Labour.—The successful operation of this furnace depends very largely upon the head melter. The quality of the product, the rate and regularity of output, and the condition of the furnace and producer are also influenced by his skill and care. Sometimes he is paid on tonnage, or at a fixed rate per shift, and sometimes on a fixed weekly wage. Whatever system of payment be adopted, the earnings of the head melter are from £3 to £4 per week. In addition to the melter, the men required to operate the furnace are as follows :—

One assistant melter.
One man at gas producer (day shift).
One man at gas producer (night shift).
One charge wheeler.
One man at boiler.
One man patching and repairing ladles.
One man at crucible furnace.
Part of one man's wages on crane.
Part expenses of chemist and management.

With an output of 1200 tons per year, the average cost of labour, including the above items, per ton of steel melted = 18*s.*

Cost of Raw Materials.—To manufacture steel to comply with the British standard tests of 28 to 30 tons tenacity with 20 per cent. elongation on 2 ins., and to give a bend of 90 deg. on a test bar of 1 in. square section, it is necessary to use good raw materials, and to aim at producing a steel having an analysis of 0·25 per cent. carbon, 0·3 per cent. silicon, and 0·75 per cent. manganese. Various kinds of scrap and pig charges will produce this result. A mixture of very low carbon mild steel scrap with the required proportion of pig will give the result by simply melting and adding the necessary manganese. A mixture of pig and scrap of differing proportions may be used, and with the addition of ore or pig iron during the " boil," the desired carbon can be obtained.

In addition to the pig iron, scrap, ore, and limestone, ferro-alloys are required. The total cost of raw materials per ton of steel melted, taken over a period of about 12 months, and allowing for a 10 per cent. loss in melting = £3 12*s.* 6*d.* per ton of steel in ladle when pig iron is 65*s.* and scrap steel 55*s.* per ton respectively. The average cost of melting the finals, including the cost of crucibles and fuel in melting, is about 3*s.* per ton of steel.

Summary of Costs

Cost of plant, £1800.

	£	*s.*	*d.*
Depreciation and interest	0	4	6
Repairs	0	5	10
Fuel	0	8	0
Labour and management	0	18	0
Raw materials	3	12	6
Melting ferro-alloys	0	3	0
Cost per ton of liquid steel	£5	11	10

Open-hearth Acid and Basic Furnaces of Larger Capacity for Foundry Work

There is practically no difference between the method of operating a large open-hearth furnace, whether it be employed in the manufacture of steel for castings or in making steel for ingots.

In distinguishing between the small and large foundry open-hearth furnaces, the chief difference lies in the heavier auxiliary plant which is necessary to handle the larger charges of steel produced. Everything about the plant is correspondingly larger, and the cost of equipment is therefore greater. In some foundries which are attached to steel works where numerous heavy castings are required for mill rolls, couplings, spindles, pinions, etc., removable furnace tops are used to admit of lifting heavy scrap castings on to the furnace hearth, without the necessity of breaking the scrap into pieces which will pass through the doors of the furnace. Loose furnace tops are unnecessary in ordinary ingot steel production, as it is more profitable to use scrap of convenient size, which can be handled by the machine charger and fed into the furnace through the doorways.

Rate of Production.—The rate of output from 25 to 40-ton furnaces when making steel for castings is from 1½ to 2 heats per 24 hours. Twelve heats per week in Britain is considered very good practice; usually 11 heats is a more common number. The time taken per heat varies, according to the nature of the charge and the quality of the steel desired. The method of charging furnaces also is more commonly done by hand, the time taken per heat thereby being prolonged.

Cost of Acid and Basic O.-H. Steel Production in Steel Foundries.—In a paper[1] given by Prof. Bradley Stoughton before the American Foundrymen's Association the following figures for acid and basic open-hearth furnace steel costs are given :—

TABLE LXXXVI

Acid Process

Prices of raw materials are based upon the current prices of materials in Pittsburg during the first week of May, 1909.

Raw materials.	Price of raw materials per 2000 lbs.	Weight used.	Percentage used.	Cost, 25-ton furnace.	Cost.
	£ s. d.	lbs.		£ s. d.	£ s. d.
Pig iron	2 18 4	300	15	8 9	
Heads, gates, etc. .	2 18 4	660	33	19 3	
Foreign scrap . . .	3 0 5	1080	54	1 12 7½	
Defective castings. .	10 8 4	20	1	2 1	
Ferro-alloys . . .	8 6 8	29	1	2 5½	
Total cost of metal		2089	104	3 5 2	3 5 2
Operating costs for 25-ton furnace				1 2 11	
,, ,, small furnaces					1 16 10½
Total cost of steel in ladle per 2000 lbs.				4 8 1	5 2 0½
,, ,, ,, 2240 lbs.				4 18 8	5 14 3

[1] "Transactions American Foundrymen's Association, vol. 28, pp. 31–38.

TABLE LXXXVII

BASIC PROCESS

Prices of raw materials are based upon the current prices of materials in Pittsburg during the first week of May, 1909.

Raw materials.	Price of raw materials per 2000 lbs.	Weight used.	Percentage used.	Cost, 25-ton furnace.	Cost.
	£ s. d.	lbs.		£ s. d.	£ s. d.
Pig iron	2 13 1½	1040	52	1 7 7½	
Heads, gates, etc.	2 18 4	660	33	19 3	
Foreign scrap	2 6 5½	350	17·5	8 1½	
Defective castings.	10 8 4	40	2	4 2	
Ferro-alloys	8 9 2	33	1·5	2 9½	
Total cost of metal		2123	106	3 1 11½	3 1 11½
Operating costs for 25-ton furnace				1 5 5	
,, ,, small furnaces					1 19 9½
Total cost of steel in ladle per 2000 lbs.				4 7 4½	5 1 9
,, ,, ,, 2240 lbs.				4 17 10½	5 13 11

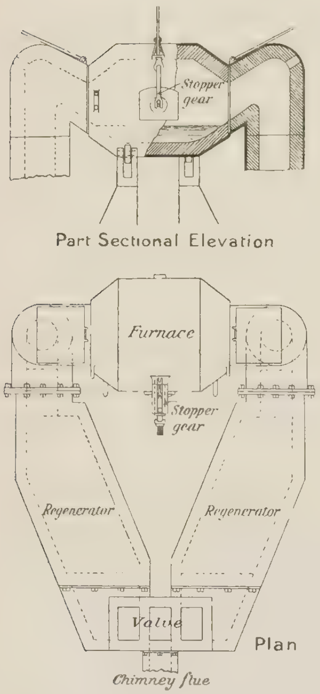


FIG. 213.—Small Oil-fired Open-hearth Furnace with removable hearth. (Carr's design.)

From these comparative costs it will be observed that there is little difference between the total costs of acid and basic open-hearth steel, although the operating costs of the basic are higher than those in the acid practice. These costs would have been of more service by way of comparison had the operating costs been subdivided into labour, fuel, materials used in repairs, etc. They represent, however, the costs for the charges in question, and approximate what may be regarded as fairly accurate operating costs, for ordinary open-hearth practice, with the sizes of furnaces given.

OIL-FIRED OPEN-HEARTH FURNACES FOR STEEL FOUNDRIES

The use of oil-fired open-hearth furnaces is confined chiefly to the districts where oil is plentiful and more economical for steel manufacture than other kinds of fuel available. For all sizes of furnaces, oil can be profitably employed. In steel works where large furnaces are connected with an oil supply, it is usual to have gas producers in reserve, to be put into operation should the oil supply fail or the price be raised to a figure which would make the use of producer gas more economical.

1000-lb. Oil-fired Open-hearth Furnace.—The development of the oil-fired open-hearth furnace for foundries has taken place principally in America. Some very small plants are in operation there. The following particulars [1] of cost are of a small open-hearth revolving furnace of 1000 lbs. capacity, as illustrated in Fig. 213. The furnace is equipped with one set of air regenerators only. The body of the furnace can be removed from between the uptake flues, and the steel tapped from it as from an ordinary bottom-stoppered ladle.

To insure the intermittent use of the furnace without undue expansion and contraction, Mr. Carr, the designer, suggested a lining of refractory fireclay bricks instead of silica bricks. As the number of heats obtained from one lining is not given, it is somewhat doubtful whether fireclay bricks would last very long. They are certainly better for intermittent use than silica bricks, which chip off, split, and waste in other ways when used intermittently. Again, fireclay bricks are less costly, and with a drum type of furnace, as shown in Fig. 213, which can be removed from between the uptakes by a crane, the renewal of a lining need not be an expensive matter. The following costs of production are given :—

1000-*lb. Open-hearth Furnace Costs*

Output—4 heats per working day. Each heat 1000 lbs.

		£	s.	d.
Pig iron charged . .	1260 lbs. @ 83*s*. 4*d*. per ton =	2	6	10½
Steel scrap	2940 „ @ 75*s*. „ =	4	18	5
	4200 „	7	5	3½
Deoxidisers		0	9	4½
Labour—				
1 melter @ 16*s*. 8*d*. per day				
1 helper @ 6*s*. 3*d*. „				
22*s*. 11*d*.		1	2	11
Fuel, 88 gallons @ 1½*d*. per gallon		0	11	0
Steel produced, 4000 lbs. Loss, 5 %. Cost . .		£9	8	7

Cost per short ton (2000 lbs.) = £4 14*s*. 3½*d*.
Cost per ton (2240 lbs.) = £5 5*s*. 7*d*.

Cost of Installing Oil-fired Open-hearth Furnaces.—The cost of installing oil-fired furnaces in foundries is not so great as that of ordinary open-hearth furnaces with gas producers. It is estimated [2] that for single furnaces between 5 and 25 tons capacity, £200 per ton capacity for acid-lined furnaces, and £250 per ton capacity for basic-lined furnaces, are average figures. These prices per ton capacity include excavating, brickwork, castings, structural material, including stack, but do not include the platform or facilities for charging. A 5-ton basic furnace would therefore cost £1250 for the above-named items, but an additional cost of about £800 would be entailed for furnace platform, oil storage tanks, pumps, oil piping, burners, etc. The buildings are not included. The prices are for normal conditions of site, and would require modification for special conditions.

[1] "Iron Age," Feb. 11th, 1909, p. 465. [2] "The Foundry," vol. 30, p. 179.

15-TON OPEN-HEARTH OIL-FIRED ACID FURNACE

Description of the Furnace.—In Fig. 214 is shown a sectional elevation and plan of an oil furnace in operation at a Wisconsin steel foundry in Milwaukee, Ohio, U.S.A.[1] It is perhaps one of the most modern furnaces of this type used in a steel foundry. Two furnaces are installed, one of 5 tons, and the other of 15 tons capacity. They are of novel design for steel foundry operations, both being made after the Campbell tilting furnace type, with specially arranged uptake ports, just as in the larger types of furnaces. They are built on the Swindell patents. The sizes of the 15-ton furnace are as follows :—

Overall length	38′ 7″
Width	12′ 0″
Height	9′ 9″
Uptakes (depth)	5′ 3″
Tilting hearth (length)	28′ 0″

There are three doors, each 3 feet square, with sills 2 ft. 3 ins. above the charging floor. The doors are operated hydraulically, and the door frames are water-cooled.

Auxiliary Furnace Plant.—For charging the raw materials in the furnace a hand charging machine is used, but the pig iron and scrap are brought to the charging platform by a 2½-ton Pawling & Harnischfeger electric mono-rail travelling hoist from the stockyard. The traveller picks up the pig iron and scrap from their independent stacks and puts them in the charging boxes on the cars for removal to the furnace. By this means, the charging of the furnace is greatly facilitated.

Output of the Furnace.—It is stated that the 15-ton furnace working alone can produce 100 tons of steel in 24 hours. This equals 6 to 7 heats per double shift. Smaller heats of 12 tons and 7 tons take 4 hours and 3½ hours respectively. Considering the output from the furnace when operated on day shift only (which is the most common practice in foundry work), 3 heats per day is a possible maximum when the materials are charged each morning about 1 a.m. and melted ready for testing between 6 and 7 a.m. A second heat might be ready by 1 p.m., and a third by 6 p.m. This, however, would allow no time for refining the charge, and only selected pig and such scrap could be used as would produce the temper of steel required. At this rate of working, the lining could receive but scant repairs between heats, hence more frequent rebuilding of the furnace would be necessary. An illustration is given of a charge melted in 3½ hours, consisting of the following materials :—

3000 lbs. of pig iron.
9280 lbs. of various kinds of scrap.
80 lbs. of ferro-silicon.
130 lbs. of ferro-manganese.
300 lbs. of iron ore.
300 lbs. of sand.
2 lbs. of aluminium.

The analysis of the steel obtained from the mixture was as follows :—

C, 0·24% ; Si, 0·39% ; Mn, 0·81% ; P, 0·049% ; S, 0·033%.

From the particulars given, both the pig and scrap must have been very free from sulphur.

Assuming, therefore, that the charges are produced at the rate of 3 heats

[1] "The Foundry," Nov. 1911.

per day, working continuously for 5 days per week and 2 heats on Saturdays, a weekly tonnage of 255 tons of liquid steel is possible from one 15-ton furnace.

Cost of Furnace and Plant.—The particulars of cost of the Milwaukee plant

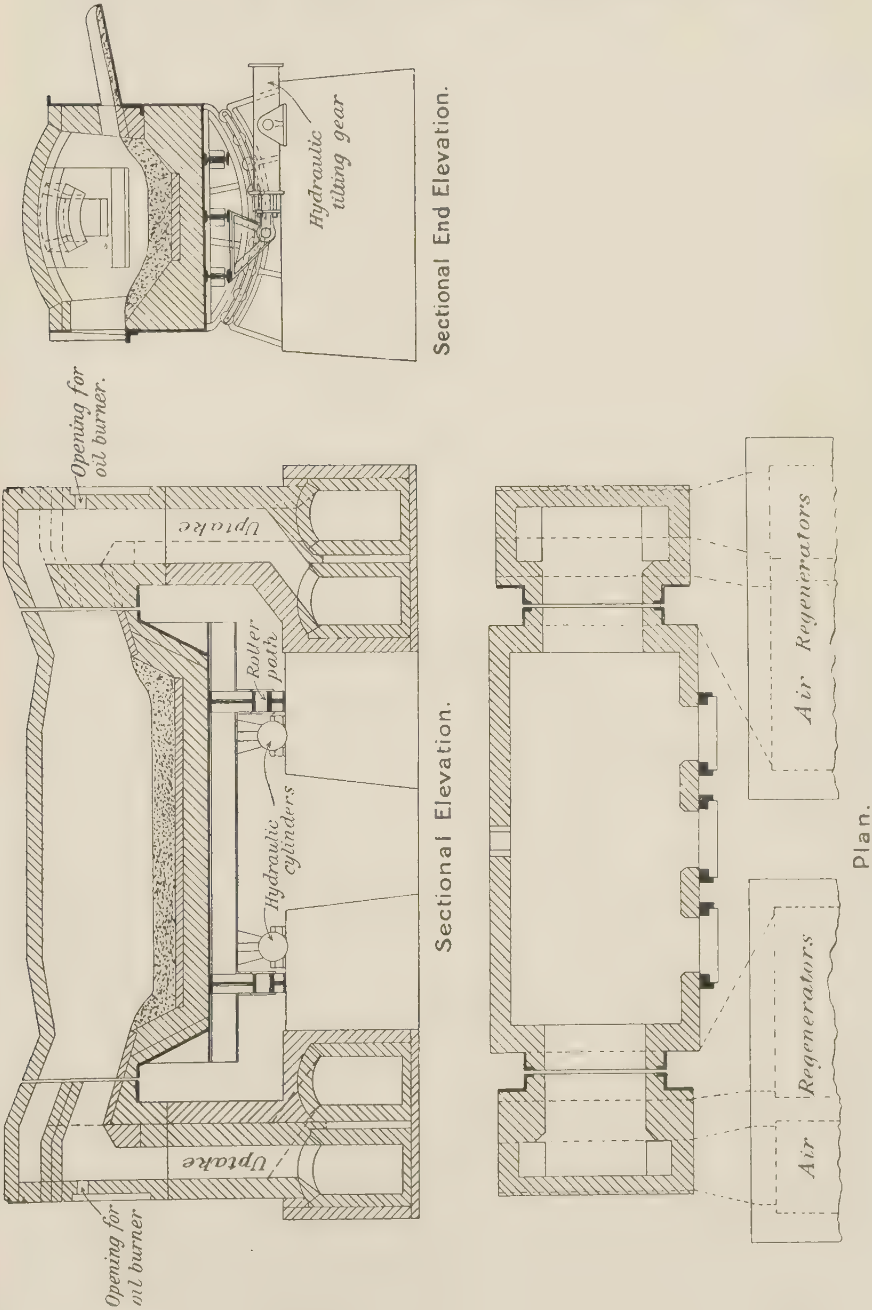


FIG. 214.—15-ton Oil-fired Tilting Open-hearth Furnace. Acid-lined.

are not given, but considering the 15-ton furnace plant only, with the necessary equipment such as the following, the approximate cost is estimated at £10,000.

1. One tilting furnace of 15-tons capacity with gear and water-cooling equipment.
2. Oil burners and tanks, air compressors and all apparatus and storage facilities for tanks.
3. Charging apparatus for stockyard and furnace.
4. Crane in casting shop.
5. Ladles, trucks, charger boxes, slag pans and trucks, weighbridge, etc.

Allowing 15 per cent. of this amount for depreciation and interest, the annual charge = 15 per cent. of £10,000 = £1500.

As the furnace would run for about three months and then be set down for about a month for repairs, the yearly campaign of the furnace would be approximately 40 weeks. Yearly output therefore = $255 \times 40 = 10{,}200$ tons.

∴ Charge for depreciation and interest per ton of liquid steel

$$= \frac{1500 \times 20}{10{,}200} = \text{approx. } 3s.$$

Working Costs of the Furnace

Repairs.—There are small repairs going on all the time the furnace is in operation, such as patching the bottom between heats, repairs to brickwork and the machinery operating the furnace and its equipment, renewal of hand tools, and also the general repairs of the furnace. It is stated that 266 heats can be obtained from the furnace without general repairs. The roof will stand 800 heats and the back wall 630 heats without overhauling. The total cost of all materials for repairs is estimated at 4*s.* 6*d.* per ton of steel.

Fuel.—Two oil burners supply the fuel to the furnace under a pressure of 80 lbs. per square inch. The oil consumption is about 50 gallons per ton of liquid steel. Crude oil was purchased in 1911 in Milwaukee at from 1*d.* to $1\frac{1}{2}d.$ per gallon. Since then, the price has increased. Taking the price at $1\frac{1}{2}d.$ per gallon, the cost of oil per ton of steel = 6*s.* 3*d.*

Coal for boilers supplying steam for air compressor, also pumps for water cooling, and heating ferro-additions = 1*s.* 2*d.* per ton of steel.

Labour.—The labour per shift is as follows:—

	s.	*d.*
One melter	20	0
One first hand	12	0
One second hand	7	0
One charger	8	0
One crane man	12	0
Two pit men @ 7*s.* each	14	0
Six labourers handling scrap, pig, sand, ore, etc., @ 5*s.* 6*d.* each	33	0
Four labourers removing slag and generally assisting at furnace, @ 5*s.* 6*d.* each	22	0
Six night-shift men removing scrap, slag, etc., from furnace and charging during early morning, @ 7*s.* each	42	0
Chemist (equivalent)	18	0
Total wages	188	0 per shift.

$$\therefore \text{ Cost of labour per ton of steel} = \frac{188}{45} = 4s.\ 2d. \text{ approx.}$$

The labour for repairs, including the partial services of men at boilers, air compressor, grinding mill, and general repairs to tools, plant, etc., is estimated at 1*s.* 3*d.* per ton of steel.

∴ Total cost of labour (operating and repairs) = 5*s.* 5*d.* per ton.

Raw Materials.—Allowing for a 10 per cent. loss in the materials charged, and an average price of 65*s.* for the pig iron and scrap used, the cost of materials per ton of liquid steel, including for fluxes and additions, is approximately, £3 12*s.* 6*d.* It is assumed that the additions are heated and added to the bath in a solid form. Sometimes the ferro-manganese is added to the casting ladle, when the amount is not considerable and is likely to melt quickly.

General Expenses and Office Charges.—This charge is taken at a nominal figure of 1*s.* 9*d.* per ton of steel, as it must vary according to arrangement of plant and management.

Summary of Costs

Per ton of liquid steel for the production of 255 tons of steel weekly from 15-ton acid open-hearth tilting furnace.

Cost of furnace and plant (estimated), £10,000.

	£	s.	d.
Depreciation and interest	0	3	0
Repairs (materials only)	0	4	6
Fuel (oil)	0	6	3
,, (coal)	0	1	2
Labour (operating and repairs)	0	5	5
Raw materials	3	12	6
General expenses and office charges (share)	0	1	9
Total cost per ton of liquid steel	£4	14	7

CHAPTER XXXV

THE TALBOT CONTINUOUS PROCESS

THE Talbot continuous process of steel making was introduced by Mr. Benjamin Talbot at Pencoyd, Pennsylvania, over 13 years ago, and in this country at the Frodingham Iron and Steel Co.'s works in 1902. Since then it has been adopted in many steelworks in different countries. Table LXXXVIII (on p. 390) gives a list of furnaces in operation and being built, with the approximate analyses of the pig iron used in the furnaces.

The Talbot process is essentially a rapid converting basic open-hearth process, in which molten phosphoric pig iron is used instead of cold pig and scrap. The first charge consists of a very liberal proportion of mild steel scrap, which is gradually melted from the cold state. Likewise are the charges after each furnace run, which may be at the end of one or several weeks. It is advisable to completely empty the furnace as seldom as possible, for the sake of maintaining a good output and keeping the tapping temperature at the uniform heat required. In practice, the furnace is now rarely completely emptied, a certain amount of metal being kept in over the week-ends.

Higher percentages of iron oxides, such as mill scale and iron ore, can be used in this process than in the ordinary pig and ore process, because of the use of fluid iron charges, consequently a better yield of finished steel is obtained by the reduction of iron from the fluid slag. The use of lime and iron oxide for the removal of impurities from the charge are as necessary in this method of manufacture as in the ordinary basic open-hearth furnace, but with the tilting furnace the slags which are formed can be poured off whenever desired. In practice, a large part of the slag is poured off sometime before the finishing of the heat, and a new slag made by suitable lime and oxide additions. This new slag is not poured off when the furnace is tapped, as it is comparatively pure, and is carried forward to help to purify the next heat. This carrying forward of a good slag is one of the advantages of the Talbot Process.

The proportion of the charge poured into the casting ladle at one time varies according to requirements and circumstances. At the works of Messrs. Jones and Laughlin, Pittsburg, 50 tons of steel are taken at a time from the 200-ton furnaces, and 80 tons from the 250-ton furnaces. Where furnaces of smaller capacity are serving electric furnaces, smaller proportions of the total charge may be taken, such as 5 tons from a 50-ton furnace.

The ease with which the process can be conducted admits of sufficient flexibility to allow of its wide application in steel manufacture.

Description of the Furnace.—The Talbot process can be carried out in tilting furnaces such as are shown in Fig. 215, and which differ only in a few vital details from the original Campbell and Wellman furnaces. The body of the furnace (consisting of a steel or iron built-up frame lined with refractory material), is mounted upon rollers which move in circular tracks securely bolted

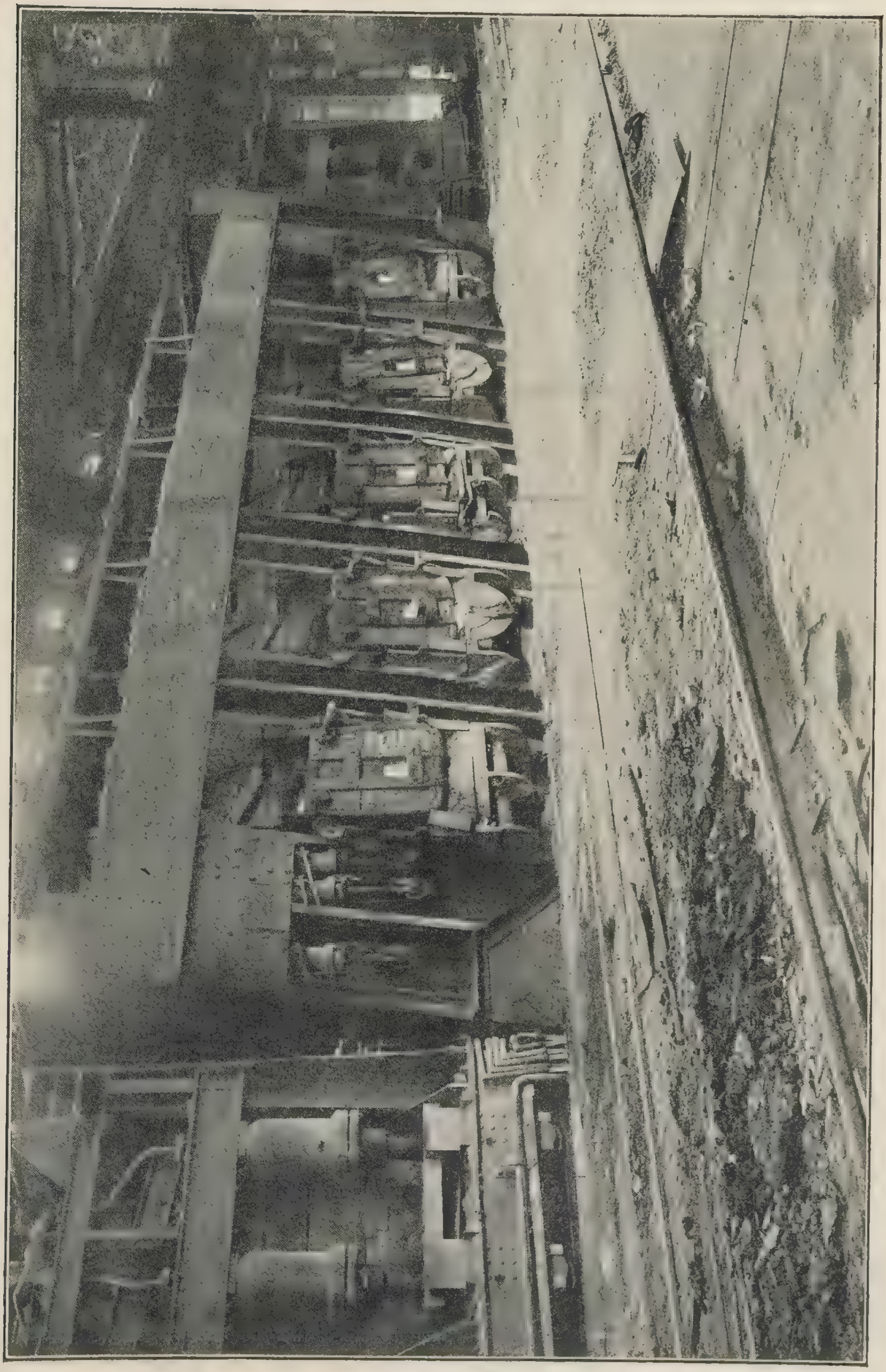


Fig. 215.—Talbot Furnace. Charging platform.

TABLE LXXXVIII

DETAILS OF TALBOT PLANTS

Name of Works.	No. and capacity of furnaces.	Percentage composition of pig iron.					Output per furnace in 24hours.	Remarks.
		C	Si	Mn	P	S	Tons	
Cargo Fleet Steel and Iron Works, Middlesbrough . .	3 of 175 tons 2 of 200 ,,	—	0·8–1·25	0·8–1·0	1·3–1·5 up to 2·0	0·08–0·12	200 225	Two converter-shaped 150-ton mixers heated by coke-oven gas.
Frodingham Iron and Steel Works, Scunthorpe . . .	1 of 100 ,, 2 of 150 ,,	—	0·5–1·0	1·5	2·0	0·04–0·12	160	No mixer.
Guest, Keen and Nettlefolds Ltd.,[1] Dowlais Iron Works, Cardiff	1 of 170 ,,	—	1·25	1·25	0·07	0·05 0·07	240	No mixer.
Palmer's Shipbuilding and Iron Co., Ltd., Jarrow . .	2 of 170 ,,	—	1·0	0·5	1·5–1·75	0·1	—	One Talbot furnace as mixer.
Skinningrove Iron Co., Ltd., Skinningrove	1 of 250 ,,	—	1·0–1·25	—	1·4	0·08	—	Building.
South Durham Steel and Iron Co., Ltd., W. Hartlepool	2 of 170 ,,	—	1·0	—	0·05	0·05	—	Charged with hematite.
Jones and Laughlin Steel Co., Pittsburg, U.S.A. . .	9 of 200 ,, 4 of 200 ,,	—	1·0–1·1	0·6	0·5	0·1–0·15	—	250-ton mixer. At the Aliquippa Works of Jones and Laughlin the furnaces are fed from the converters.
New York State Steel Co., Buffalo, U.S.A.	2 of 200 ,,	—	—	—	—	—	—	
Pencoyd Iron Works, Philadelphia, U.S.A.	1 of 75 ,,	—	1·0	0·6	1·0	—	65	
Société Métallurgique de Senelle-Maubeuge, Senelle, France[2]	1 of 175 ,,	—	0·5	1·2	2·0	0·1	165	
Witkowitzer Bergbau: Witkowitz, Austria	1 of 200 ,,	—	1·0	2·0	0·4	0·08	—	

[1] This and one other English works use hematite pig in the Talbot furnace. The yield in Cardiff is proportionally higher (108%). The consumption of lime is only 4% per ton of steel; ore, etc., consumption = 25%; ferro-manganese consumption = 0·5%.

[2] At present closed down.

FIG. 216.—Wellman Furnace, tilted by Electric Motor.

to foundations. The body is tilted without disturbing the relation of the ports in it with those in the fixed ports of the furnace. The tilting is performed by means of an electric motor through suitable gearing, see Fig. 216, which gives absolute control over the furnace. The furnace can be tilted both ways, so that slag can be taken from either side as desired. Other methods of tilting are also adopted, such as hydraulic cylinders and rams, as shown in Fig. 217, and these are in general use in England, but many prefer the electric instead of the hydraulic tipping gear. By the use of the former, the inconvenience of frozen pipes in winter is eliminated. The furnace doors are also raised by electric motors, each door having its own motor, which operates, through pinion and worm gear, the crank for lifting the door. Hydraulically operated doors are also employed.

Regenerators.—The regenerators are placed at each side of the furnace and below the platform. The gas and air flues from the regenerators terminate in a movable port, which conveys the gas and air to the furnace. There is nothing special in the construction or position of the regenerators, as the regenerators in all modern open-hearth fixed furnaces are usually arranged in a similar manner. There is, however, a distinct feature in the movable ports, which is a considerable improvement upon those used in the earlier designs of tilting furnaces. The joint between the uptake flue and the movable port is water-cooled and water-sealed, preventing any escape of gas when a lateral movement of the port is occasioned by tilting the furnace.

Regarding the sizes of regenerators in relation to the furnace hearth capacity, it is stated[1] that the Talbot process can be efficiently conducted in a furnace of 175 tons capacity with regenerators, valves, stack, etc., of the same sizes as are used in a modern 60-ton open-hearth fixed furnace, and in some cases the regenerators are even smaller than in the so-called 50 or 60-ton furnaces.

Fuel used in Talbot Furnaces.—The application of any gas or liquid fuel is just as simply effected with the tilting furnace as with the fixed furnace. Many of the modern furnaces built in America are arranged for the use of natural gas or oil, in addition to ordinary producer gas. It is found more economical to use natural gas in some districts than to generate producer gas. Oil pipes and natural gas pipes are carried to the ports of the furnaces in such a manner that when they are out of use no inconvenience is experienced.

Lining the Furnace.—The lining of the Talbot furnace differs only in detail from the basic lining for fixed furnaces. The bottom is built of basic materials, and the sides above the door sills and the roof are of silica brick. On the tapping side, however, the magnesite bricks extend nearly up to the spring of the roof. The depth of the bath is greater than that of the ordinary fixed furnace.

Operation of the Furnace.—The successful operation of the Talbot furnace depends to a large extent upon the management of the slags and the metal in the furnace prior to the additions of fluid pig iron. When from a furnace of, say, 200 tons capacity, 50 tons of low carbon steel has been tapped, the furnace is tilted back into its normal position and additions are made by the electric charger of oxides (such as ore or mill scale) and lime, amounting to about 5 tons and 1½ tons respectively. These additions are allowed to melt and become absorbed in the existing slags. While this is taking place, repairs to the slag line of the furnace are carried out, after which about 25 tons of pig iron are taken in a ladle direct from the mixer by an overhead electric crane and poured slowly into the furnace. Immediately the metal enters the bath a violent reaction ensues between the impurities in the pig iron and the highly oxidised slags. The carbon is very rapidly eliminated from the metal in the form of CO,

[1] "Iron Age," vol. 77, p. 1670.

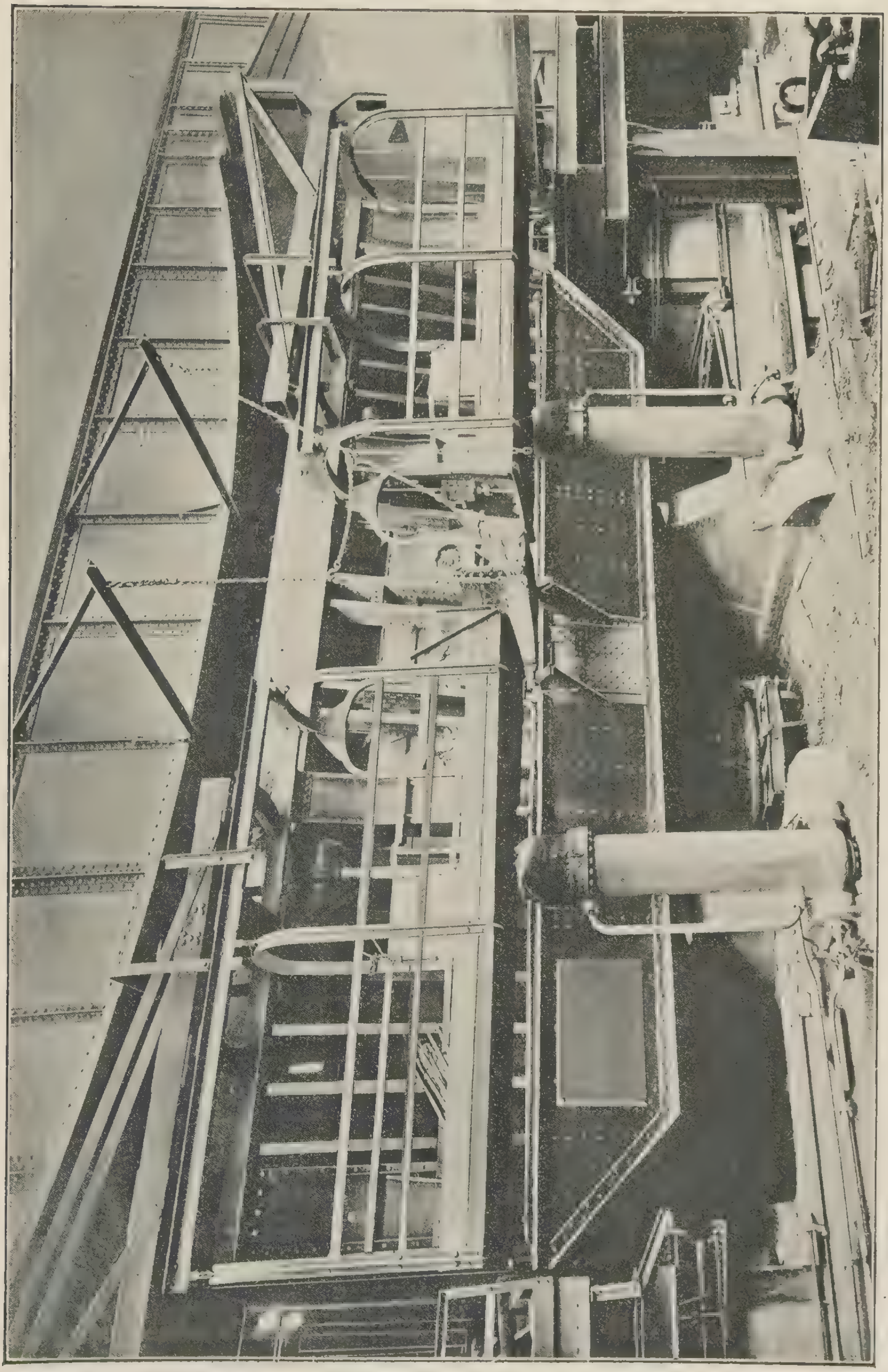


FIG. 217.—Wellman Furnace, tilted by hydraulic cylinders and rams.

and burns to CO_2, causing a temporary increase in the heat of the furnace. During this period the gas is reduced and sometimes shut off, air only being admitted to the furnace. During the reaction, the phosphorus, silicon, and manganese in the iron are oxidised, and pass into the slags, while the iron oxide in the slag is reduced and the iron passes into the metal in the bath.

The same operation is repeated again after the metal in the bath has become calm. Oxides and lime are added and afterwards a second charge of fluid metal. It is found advisable to add the fluid iron to the bath in two operations so as to keep in check the violence of the reactions, otherwise slag might be thrown from the furnace upon the staging, the loss of which at that period of the operation might retard the oxidation of the impurities. On the other hand, it is necessary to obtain a good reaction each time the fluid metal is added to the bath, otherwise it becomes a slow operation to work down the carbon, and in some instances may prove to be no more rapid than the same operation in the ordinary open-hearth furnace.

In addition to working all molten pig iron, the Talbot Process readily adapts itself to the use of scrap, and in practice the question whether the current scrap of a steel-works shall be sold as scrap or used up again in the Talbot furnaces, depends upon the commercial value of scrap in the open market.

Dimensions of Hearth.—Table LXXXIX gives a few sizes of the melting hearths of typical furnaces now in use.

TABLE LXXXIX

DIMENSIONS OF HEARTHS OF TALBOT FURNACES

Furnace.	Capacity. Tons.	Length.	Width.	Depth to foreplate.	Surface area. Square feet.
Cargo Fleet, England . . .	175 to 200	37′ 6″	14′ 6″	3′ 0″	544
Skinningrove, ,, . . .	250	43′ 0″	15′ 6″	3′ 0″	666
Senelle, France	160	50′ 10″ [1]	23′ 0″ [1]	—	—
New York State Steel Co., U.S.A.	200	53′ 0″	16′ 0″	—	848
Jones and Laughlin, U.S.A. .	200	40′ 0″	16′ 0″ [2]	—	640
Frodingham, England .	100	32′ 0″	12′ 6″	—	400
Pencoyd, U.S.A.	70	30′ 0″	9′ 0″	—	270

[1] Over all dimensions.
[2] Hearth oval in shape, 17′ 6″ at centre and 14′ 6″ at ends.

Removal of Slag.—After the second reaction, it is usual to pour part of the slag away, otherwise it becomes unwieldy and accumulates on the surface, preventing to some extent the heat from getting at the metal in the bath. The pouring is done from the charging side of the furnace into slag ladles, conveniently placed by the side of the furnace for easy removal.

Tests taken.—When the metal in the bath appears to be about ready, test samples are taken and rapid analyses made for carbon, phosphorus, and sulphur; if these are satisfactory, the desired amount of metal to form the casting charge is tapped from the furnace.

Composition of the Charge.—One of the features of the Talbot process, says Mr. Talbot,[3] is that it permits of the use of a cheaper blast furnace metal than can be employed in the ordinary open-hearth process, as a greater range of impurities can be allowed when additions of only 10 per cent. of impure metal

[3] "Iron Age," vol. 79, p. 656.

are absorbed in a bath of 90 per cent. of pure metal. The following are analyses of some of the pig irons used in the Talbot furnace :—

	Si	Mn	P	S
Jones and Laughlin [1]	1·0 to 1·25%	0·65%	0·1%	0·06%
Frodingham Iron and Steel Co. [2]	0·75 to 1·25%	2·0%	1·75 to 2·0%	0·06%
Cargo Fleet [3]	1·25%	0·8%	1·5%	0·08 to 0·12%

Some grades of iron react more violently than others when they are poured into the bath of decarburised metal; good white basic iron is not so violent as an iron with high silicon content, or very grey iron.

Rate of Oxidation of Impurities during the Reactions.—This is shown clearly from the details of charges Nos. 12,677 and 12,697 made in the 200-ton Talbot furnace at the works of Messrs. Jones and Laughlin.[4] Referring to one action only in charge 12,677, the amount of carbon given off is very well illustrated. To the furnace containing 322,560 lbs. of metal were added 10,800 lbs. scale at 11.13 a.m. and 3225 lbs. of lime at 11.34 a.m. At 12.5 p.m. the analysis of the bath gave the following :—Carbon, 0·06 per cent.; phosphorus, 0·009 per cent. Five minutes later, 46,000 lbs. of fluid iron were poured into the furnace, raising the percentage of carbon of the entire metal to 0·55. The analysis of the added metal was as follows :—carbon, 4·0 per cent.; silicon, 0·9 per cent.; phosphorus, 0·10 per cent.; sulphur, 0·06 per cent. At 12.17 p.m., that is 7 minutes after the metal was added, the carbon in the whole bath was reduced to 0·44 per cent. In other words about 400 lbs. of carbon was converted into combustible gases in 7 minutes, resulting in a very considerable generation of heat. During this period the metal in the bath was in a very violent state of ebullition, but calmed down afterwards, when the rate of oxidation of the carbon and other elements went on more slowly. More oxide and lime were added, and another 45,400 lbs. of fluid metal poured in, with an attendant repetition of the same characteristics as before, although with less violence. Finally at 3.5 p.m., the analysis of the bath before tapping was :—carbon, 0·26 per cent.; phosphorus, 0·023 per cent. The total time taken during the heat was 3 hours 57 minutes, from the commencement of charging to the moment of tapping.

Reduction of Iron from the Slag.—During the whole liberation of the carbon in the reaction expressed by the formula

$$Fe_3O_4 + 4C = 4CO + 3Fe$$

the oxide of iron in the slag is reduced to swell the metal in the charge. This is one of the special features of the process. Referring to the charge No. 12,677 mentioned above, the analysis of the slag at 12.15 p.m. gave 31·74 per cent. of iron and 12·20 per cent. of silica; at 3.5 p.m.—just before tapping the charge—the slag contained 9·06 per cent. of iron, 24·4 per cent. silica, and 40·90 per cent. lime. It is not stated how much slag was poured off during the period, but whatever the amount it would be richer in iron than that present in the remaining slag, so that additions of iron from the slag to the bath are not truly represented by the analyses given. From more recent practice, it is usual to obtain from 107 to 108 per cent. of the metal charged, as a result of the yield of iron from the oxide in the slags. The slags poured off contain from 9 to 12 per cent. of iron in the form of ferrous oxide. This slag is practically free from metallic iron.

[1] "Journal Iron and Steel Institute," 1903, I, p. 59.
[2] *Ibid.*, p. 63.
[3] "Journal West of Scotland Iron and Steel Institute," vol. xiii, pp. 75–82.
[4] "Journal Iron and Steel Institute," 1903, I, pp. 72, 73.

Chemical Changes in the Charge.—In Table XC,[1] the actual details of materials used for one charge and the time taken during the process, as well as the analyses of the metal and slags at different periods, illustrate clearly the rapidity of the process and the chemical changes which take place.

Talbot Process. Cost of Steel in Ladle

Output of Furnace.—With a 200-ton furnace and equipment, an average of from 1200 to 1400 tons of steel can be produced weekly for 45 weeks during the year. If non-phosphoric pig iron be used, an output of 1300 to 1500 tons per week is obtained. Although a furnace of the above capacity will produce from 1200 to 1500 tons weekly, the lower figure is taken for estimating the cost of production, and on this basis the annual output will therefore be 1200 × 45 = 54,000 tons of steel.

Cost of Furnace and Equipment.—With reference to the cost of furnace and equipment for working the Talbot continuous process, Mr. Talbot stated[2] that the capital cost per ton capacity for his furnace would be probably less on a large plant, and in any case would not be more than for, say, a modern 50-ton American fixed open-hearth furnace plant. As it would require two 50-ton fixed furnaces at a total equipment cost of £47,700 (see Chapter XXXIII, p. 366), to produce 1200 tons of steel per week, the cost of one 200-ton Talbot furnace with equipment would be, according to Mr. Talbot's estimate, approximately £47,700.[3] This figure is, of course, subject to variation according to the local and other conditions of site, but is taken as a basis of calculation.

Taking 10 per cent. for depreciation and 5 per cent. for interest on capital, the annual charge = 15 per cent. of £47,700 = £7155.

∴ Charge for depreciation and interest per ton of liquid steel

$$= \frac{7155 \times 20}{54,000} = 2s.\ 8d.$$

Cost of Repairs.—The cost of repairs to a Talbot furnace can only be taken approximately, as it varies according to the working of the furnace. Since Mr. Martin gave the cost as 58·3 cents. (29·15*d.*) per ton of steel melted,[4] much experience has been gained in operating the furnaces. As much as 43,000 tons of steel have been obtained from a 200-ton Talbot furnace before being put out of commission for repairs. The rapidity also with which the repairs are now effected differs from the slower methods in vogue several years ago. If, for instance, the furnace roof falls in while the metal is in the bath, the whole is allowed to cool (metal included), and a gang of 30 to 40 bricklayers is set on the job, pulling down walls and ports, and rebuilding—the whole being carried out in a few days. The furnace is then gradually heated, and the solid metal melted.

Approximately, the cost of repairs may be set down at 2*s.* per ton of steel in the ladle.

Cost of Fuel.—Mr. G. A. Wilson has stated[5] that not more than from 5 to 6 cwts. of coal per ton of ingots were required at the Cargo Fleet plant in working the 175-ton Talbot furnace. The gas was produced in Talbot producers. Figures recently obtained of coal consumption in American practice with the Talbot process show a consumption of 480 to 500 lbs. of coal per ton of steel produced.

[1] "Stahl und Eisen," vol. xxx, p. 61.
[2] "Journal West of Scotland Iron and Steel Institute," vol. xiii, pp. 90–98.
[3] This does not include cost of mixer.
[4] "Journal Iron and Steel Institute," 1903, I, p. 75.
[5] "Journal West of Scotland Iron and Steel Institute," vol. xiii, pp. 75–82.

TABLE XC

CHEMICAL CHANGES IN CHARGE C, CARGO FLEET, NOV. 16TH, 1909

Time o'clock.	Analysis of the metal. %					Analysis of the slags. %			Charge and Adjuncts.	Remarks.
	C	Si	Mn	P	S	SiO_2	FeO	MnO		
11.50	0·16	—	0·019	0·046	0·048	—	—	—	—	About 120 tons of metal in furnace.
12.0	—	—	—	—	—	9·20	15·15	5·58	—	Furnace walls repaired. 8 tons slag drawn off.
12.20	—	—	—	—	—	—	—	—	4570 kg. Gellivara ore, and 2130 kg. lime added.	
12.30	3·65	1·39	0·77	1·66	0·044	—	—	—	22,350 kg. molten pig added.	
12.55	0·40	—	—	0·058	0·037	9·00	20·57	4·83	—	
1.0	—	—	—	—	—	—	—	—	4570 kg. Gellivara ore and 2130 kg. lime added.	
1.10	—	0·93	—	1·56	0·067	—	—	—	22,350 kg. molten pig added.	
1.30	—	0·65	—	1·6	0·086	—	—	—	8130 pig added.	
2.20	0·65	—	—	0·088	0·048	11·20	14·77	2·60	—	
2.25	—	—	—	—	—	—	—	—	1020 kg. purple ore and 1270 kg. lime added.	
2.30	—	—	—	—	—	—	—	—	1020 kg. Gellivara ore and 860 kg. lime added.	
2.40	0·50	—	—	0·08	—	—	—	—	—	
2.45	—	—	—	—	—	—	—	—	860 kg. lime added.	
3.15	0·39	—	—	0·04	—	—	—	—	—	
3.40	0·28	—	—	—	—	—	—	—	—	
3.55	0·22	—	—	—	—	—	—	—	—	
4.0	—	—	—	—	—	—	—	—	860 kg. lime added. Duration of charge between tappings, 4 hrs. 30 mins.	About 54 tons steel drawn off in ladle with 430 kg. ferro-manganese (80%), 51 kg. ferro-silicon (50%) and anthracite added.
4.20	0·21	0·036	—	0·011	0·032	13·2	13·24	6·32	Composition of finished steel:— C 0·45%, Mn 0·68%, P 0·033%, S 0·04%	

Hughes producers were being used for the production of gas. Taking coal at 10*s*. per ton (although in some districts it can be purchased two or three shillings below this figure), the cost of fuel per ton of steel in ladle = 2*s*. 3*d*. approximately. Oil fuel and natural gas are used where they can be obtained at a lower cost than coal.

Cost of Labour.—With a thoroughly equipped plant for handling raw materials rapidly, no more men are required to operate a 200-ton Talbot furnace than are required for a modern open-hearth fixed furnace of 50 to 60 tons capacity, using partly liquid charges, and as the output of the former is considerably greater, the cost of labour per ton is much less. The following men are included in the wages bill for the double shift, the rates being American :—

	£	s.	d.
2 melters @ 20*s*. each per day	2	0	0
2 second hands @ 14*s*. each per day	1	8	0
4 third hands @ 9*s*. each per day	1	16	0
2 charging machinists @ 10*s*. each per day	1	0	0
4 helpers at @ 6*s*. each per day	1	4	0
4 casting-pit men @ 12*s*. each per day	2	8	0
4 crane men at 12*s*. each per day	2	8	0
2 gas makers @ 8*s*. each per day	0	16	0
8 helpers (handling coal and ashes) @ 6*s*. each per day	2	8	0
2 loco. ladle men (taking metal from mixers) @ 8*s*. each per day	0	16	0
2 mixer men @ 14*s*. each per day	1	8	0
4 helpers @ 7*s*. 6*d*. each per day	1	10	0
2 ladle men @ 8*s*. each per day	0	16	0
2 pourers @ 12*s*. each per day	1	4	0
12 labourers (handling scrap, ore, lime, limestone, fluorspar, etc.) @ 5*s*. 6*d*. each per day	3	6	0
2 loco. men removing slag @ 8*s*. each per day	0	16	0
8 helpers @ 5*s*. 6*d*. each per day	2	4	0
2 chemists @ £1 each per day	2	0	0
Total wages per shift of 24 hours	£29	8	0

$\therefore$ Cost of labour per ton of steel $= \dfrac{\pounds 29\ 8s. \times 6 \times 20}{1200} = 2s.\ 11d.$ approximately.

There are other expenses of labour, such as electrician, firemen at boilers, weighbridgemen, storemen, etc., which are not included in the above, but would add a little more, making, say, 3*s*. as the cost per ton.

Cost of Raw Materials.—The following figures are taken for the materials charged into the furnace :—

Pig iron	@ 50*s*. per ton
Mill scale and iron ore	@ 20*s*. ,,
Lime	@ 10*s*. ,,
Ferro-manganese	@ 200*s*. ,,

The raw materials used to produce 100 tons of steel in the ladle are approximately :—

			£	s.	d.
95 tons of pig iron . .	@	50s. =	237	10	0
25 ,, ,, mill scale . .	@	20s. =	25	0	0
6 ,, ,, lime . . .	@	10s. =	3	0	0
½ ton ,, ferro-manganese	@	200s. =	5	0	0
Cost of raw materials . . .			£270	10	0

∴ Cost of raw materials per ton of steel produced = approximately £2 14s.

No allowance is made for aluminium or ferro-silicon for "killing" the metal, and no deductions are made from the above cost for the value of the slag sold as manure.

Summary of Costs.

Per ton of liquid steel produced in 200-ton tilting furnace working on the Talbot process.

Cost of plant, £47,700.

	£	s.	d.
Depreciation and interest	0	2	8
Repairs	0	2	0
Fuel	0	2	3
Labour	0	3	0
Management expenses	0	1	6
Raw materials	2	14	0
Total cost per ton of liquid steel	£3	5	5

The operating costs are very low compared with other furnaces of large output.

CHAPTER XXXVI

COMPOSITION OF CHARGES EMPLOYED AND ANALYSES AND USES OF STEEL PRODUCED IN THE OPEN-HEARTH PROCESS.

THE materials used in the open-hearth furnace include pig iron, scrap iron, scrap steel, ore, scale, carbon, lime, limestone, fluorspar and other fluxes, spiegel and other ferro-alloys. Both solid and liquid pig iron are used, but the scrap steel and iron are added in the solid state. The proportions of pig iron to scrap differ according to the method of melting and refining employed. The amount of ore and scale used depends upon the oxidation required. Fluxes of limestone, lime, fluorspar, and metalliferous slags are used according to the amount of cleaning necessary in the metals, and in both the acid and basic processes the removal of impurities proceeds on much the same lines. The analyses of the pig irons and scrap used are limited only by the kind of furnace lining employed, phosphoric pig iron and scrap being melted in the basic-lined furnace. Steel scrap or wrought iron cannot be used alone, as there are insufficient reducing elements in them to promote oxidation by the action of the gases in the furnace.

Pig Irons.—In the section on pig irons, p. 14, Table X, are given analyses of pig irons suitable for the acid open-hearth process, which may be taken as typical, many varieties of pig iron being used. It is, however, necessary, in using any brand of pig iron, to see that both phosphorus and sulphur are present in very small proportions only, as their removal in the acid process is possible only to a limited extent, and even then with difficulty. In the pig irons referred to in Table X, the phosphorus and sulphur vary from 0·02 to 0·06 per cent. and 0·013 to 0·05 per cent. respectively; but sometimes pig irons are used which contain higher percentages of these elements, and in such cases it is usual to mix better brands with the poorer qualities, and to see that the amount of phosphorus and sulphur in the scrap are within reasonable limits.

With regard to the pig irons used in the basic open-hearth process, the silicon and sulphur (particularly the latter element), should be as low as possible. In the list of pig irons given in Table IX, p. 13, is to be found a fairly typical set of analyses, although the analyses of basic pig irons used in the basic open-hearth process are perhaps more varied than those of any other class of pig irons.

Scrap.—All kinds of scrap steel and wrought iron are used in the open-hearth processes, and quite a large trade is carried on in selling bundled and compressed light steel plate, hoops, steel turnings, and other miscellaneous kinds of scrap for remelting in the open-hearth furnace. It is in the use of miscellaneous scrap of this kind that sometimes troublesome material, such as tinned and coppered sheet iron, or other injurious scrap materials, find their way into the furnace. Before merchants bundle and compress scrap, an examination is made, as a rule, and objectionable scrap is removed. Light scrap, unbundled, is also used very largely, and consists of all kinds of wrought iron and steel plate croppings, punchings, and scrap of all sorts, sometimes very dirty, and containing undesirable materials. Larger scrap, such as billet ends, old

rails, heads from castings, steel works and foundry scrap, miscellaneous old steel castings, ingot moulds, and specially selected scrap, find their way into the open-hearth furnace, the medium-sized scrap being more reliable as a rule. Very heavy scrap, in the form of old steel castings, several tons in weight, is charged into furnaces where the tops can be removed; but this kind of scrap is undesirable for rapid melting.

Proportion of Pig Iron and Steel Scrap.—There is no fixed rule as to the proportion of pig iron and steel scrap which should be used in the open-hearth process. These are determined very largely by the prices of the pig iron and scrap in the locality, and by the mixture used in melting, *i.e.* whether the charge consists almost entirely of pig iron and scrap, or whether pig iron and ore are in excess of scrap steel. In some districts scrap steel is cheaper than pig iron, hence it is used more abundantly. The price of scrap, however, fluctuates considerably. Carl Dichmann,[1] in referring to the pig and scrap process in the basic open-hearth furnace, states that in the real purely pig and scrap process it is sought so to regulate the quantity of the reducing agents which are added to the charge in the form of pig iron that they contain exactly the balance for the oxidising action of the flame, and the employment of large quantities of ore is not requisite. If this has been well adjusted, the conditions for the best working results have been created.

This principle was the main feature of the Martin process, which, as is well known, consists in adding additions of scrap steel to pig iron previously melted in the open-hearth furnace, until a balance of elements produced the steel required through the partial oxidation of the impurities in the combined metal.

Charges consisting of pig iron and scrap to fulfil approximately the above conditions necessitate the careful selection of scrap; but the time required to produce each heat is reduced very considerably, and for many classes of steel the results are entirely satisfactory. In this country and in America pig iron, scrap, and ore charges are more generally used than pig iron and scrap steel charges only. The most common proportions of materials used in the ordinary pig iron, scrap, and ore process are 25 to 35 per cent. of pig iron and 75 to 65 per cent. of scrap steel, with just sufficient ore or mill scale to produce the oxidation required.

Uses of Open-hearth Steel.—With the exception of steel for the manufacture of which the crucible furnace and perhaps small surface-blown Bessemer converters only are adapted, the open-hearth furnace is capable of producing steel for all classes of work where cast, forged, and rolled steel are required. Some claim that steel for small, intricate castings, such as were formerly made exclusively by the crucible process, can be made with equal fluidity in small open-hearth furnaces. For green and dry sand castings, such as are classified in Chapter XXIII ("Materials used in Small Bessemer Converters"), Table LXII, there is no question that most of the lighter castings, if not all, can be produced from steel made in small Siemens furnaces, where high heats are obtainable. Heavier castings of all sizes and weights at present used for industrial and engineering concerns can be made also from steel manufactured in open-hearth furnaces.

The grades of steel given and the analyses of the materials used in the castings referred to in Chapter XXIII are also applicable to open-hearth steel.

The open-hearth furnace is not, however, limited to the production of steel for castings. Ingots for ship and boiler plates, rails, girders and steel sections, wire, tubes, as well as heavier work such as armour plates, gun tubes and forgings, marine crank and tail shafts, and many other purposes, form a very large proportion of the world's output of open-hearth steel. In Table XCI are given

[1] Dichmann, "The Basic Open-hearth Steel Process," p. 248.

TABLE

ANALYSES AND MECHANICAL

No.	Purpose for which steel is required.	Acid or Basic.	Analysis. C %	Si %	Mn %	P %
	Railway rails—					
1	(Bull head)	Acid or Basic	0·35–0·50	0·1 max.	0·7 –1·0	0·075 max.
2	(Flat bottom).	,,	0·35–0·50	0·1 max.	0·7 –1·0	0·07 max.
3	Railway rails	,,	0·46–0·75	0·2 max.	0·6 –0·9	0·04 max.
4	Railway rails	,,	0·7 –0·8	0·05–0·2	0·8 max.	0·03 max.
5	,, (Sandberg process) .	—	0·65 min.	0·2 –0·4	0·9 max.	0·06 max.
6	,, (Manganese steel) .	—	1·0 min.	—	11·0 –14·0	0·1 max.
7	,, (Titanium steel) . .	—	0·75–0·9	—	—	—
8	Tramway rails	Acid or Basic	0·4 –0·55	0·1 max.	0·7 –1·0	0·08 max.
9	Loco crank axles	Acid	0·25–0·32	0·2 max.	1·0 max.	0·035 max.
10	Axles and shafts	—	0·6 max.	—	0·4 –0·8	0·05 max.
11	Railway tyres	Acid	0·56–0·60	0·2	0·75	0·028
12	,, ,, ...	—	0·6 –0·7	0·25 max.	0·7	0·05 max.
13	Tramway tyres	—	0·65–0·75	0·2	0·9 –1·1	—
14	Railway wheels, forged or rolled carbon steel	Acid	0·6 –0·8	0·15–0·35	0·55–0·8	0·05 max.
15	Railway wheels, forged or rolled carbon steel	Basic	0·65–0·85	0·1 –0·3	0·55–0·8	0·05 max.
16	Wagon draw hooks . . .	Acid	0·15–0·25	0·08 max.	0·5 –1·0	0·08 max.
	Bars for—					
17	Laminated springs . . .	—	0·45–0·7	0·10 max.	1·0 max.	0·06 max.
18	Volute and spiral springs .	—	0·7 –1·0	,,	,,	,,
19	Laminated springs . . .	Acid	0·55–0·8	0·12 max.	0·8 max.	0·035 max.
20	Volute and spiral springs .	,,	0·8 –1·3	,,	,,	,,
21	Spring steel (high silicon) . .	—	0·7	1·127	0·325	—
22	Structural steel	Basic	0·25	0·02	0·5	0·04
23	Eye bars for bridges[1] . . .	—	0·25	0·12	0·32	0·02
	Structural nickel steel—					
24	Rivets	Acid or Basic	0·3 max.	—	0·6 max.	Acid 0·04 max. Basic 0·03 max.
25	Plates and shapes . . .	,,	0·45 max.	—	0·7 max.	Acid 0·05 max. Basic 0·04 max.
26	Bars and rollers (unannealed)	,,	,,	—	,,	,,
27	Bars and pins (annealed) .	,,	,,	—	,,	,,
28	Piston rods and connecting rods	—	0·26–0·34	0·15 max.	0·6 –0·8	0·05 max.
29	Steel shafts (large)	Acid	0·3	0·1	0·65–0·70	0·028
30	Gun forgings	,,	0·3	0·1	0·5 –0·8	0·03
31	Tube steel	Basic	0·1 –0·16	0·004–0·012	0·43–0·46	0·012
32	Billets for wire rope . . .	,,	0·65–0·75	—	—	0·025
33	Boiler firebox steel	Acid or Basic	0·12–0·25	—	0·3 –0·5	Acid 0·04 max. Basic 0·035 max.
34	Tinplate bars	Basic	0·12	0·037	0·412	0·047
35	Stamping steel[2]	,,	0·1	—	0·33	0·007

5, "Journal Iron and Steel Institute," 1910, II, p. 518; 6, "Electric Railway Journal," vol. 37, 1904, I, p. 67; 29 and 30, "Journal Iron and Steel Institute," 1904, I, pp. 68

[1] Bars hardened and annealed.

XCI

TESTS OF STEEL

S %		Mechanical tests. Tenacity. Tons per sq. in.	Elastic limit. Tons per sq. in.	Elongation.	Reduction of area %	Remarks.
0·08 max.	—	38–45	—	15% on 2″	—	Engineering Standards Committee Specification (1904).
0·07 max.	—	40–48	—	15% on 2″	—	Ditto (1905).
—	—	—	—	—	—	American Society for Testing Materials (1909).
—	—	—	—	—	—	Pennsylvania Railway Specification (1908).
0·07 max.	—	—	—	—	—	Rails in use by Underground Railways, London.
—	—	—	—	—	—	Interborough Rapid Transit Co., New York.
—	0·1 % Ti	—	—	—	—	
0·08 max.	—	40 min.	—	12% on 2″	—	Engineering Standards Committee Specification (1903).
0·035 max.	As 0·02 % max.	28-32	50% of tensile min.	25% on 3″	35	Indian state Railways Specification.
0·05 max.	—	38	22	22% on 2″	45	American Society for Testing Materials.
0·03	—	50–55	—	14–18% on 2″	20	Test on Vickers steel.
—	—	—	—	—	—	American practice.
—	—	54	—	8% on 2″	—	
0·05 max.	—	—	—	—	—	American Society for Testing Materials (1912).
0·05 max.	—	—	—	—	—	Ditto.
0·08 max.	—	—	—	—	—	Great Western Railway Specification.
0·06 max.	—	45–50	—	—	—	Ditto.
,,	—	—	—	—	—	Ditto.
0·035 max.	As 0·02 max.	—	—	—	—	Indian State Railways Specification.
,,	,,	—	—	—	—	Ditto.
—	—	—	—	—	—	
0·04	—	30	—	23% on 8″	—	English practice.
0·035	Ni 1·45 Cr 1·2 V 0·17	43·2	36·2[2]	29·15% on 12″	52·1	American practice.
0·04 max.	Ni 3·25 min.	31·2–35·7	20·1 min.	—	40 min.	American Society for Testing Materials (1912).
,,	,,	39 –44·6	22·3 min.	—	25 min.	Ditto.
,,	,,	42·4–49·1	24·5 min.	—	,,	Ditto.
,,	,,	40·2–47	23·2 min.	—	35 min.	Ditto.
0·05 max.	As 0·05 max. Cu 0·10 max.	—	—	—	—	British Admiralty Specification.
0·026	—	31	15·8	30% on 2″	40–44	Tests on Vickers steel.
0·03	—	40	24	20% on 2″	—	Ditto.
0·02	—	—	—	—	—	Tests on Stewarts and Lloyds steel.
0·025	—	—	—	—	—	Welsh practice.
0·04 max.	Cu 0·05 max	23·2–27·7	0·5 of tensile	—	--	American Society for Testing Materials (1912).
0·017	—	—	—	—	—	Welsh practice.
0·019	Ti 0·21	20	16·5	40% on 8″	56·4	American practice.

p. 82 ; 7, "Journal Iron and Steel Institute," 1911, I, p. 653 ; 11, "Journal Iron and Steel Institute," and 69 ; 31, "Journal West of Scotland Iron and Steel Institute," vol. II, p. 58.

[2] Annealed dead soft before testing.

the chemical analyses and mechanical tests of some classes of steel made by the basic and acid open-hearth process.

Typical Charges and Analyses of Materials used in the Acid and Basic Open-hearth Furnaces.—The following charges of materials for British, American, and German open-hearth steel, are indicative of what is used for the purposes named against each charge, but are subject to considerable variation in different works in each of the countries named.

Charge 1.—*Acid Pig and Scrap Process*

Steel for Bridge construction.[1]

Materials used in charge—

Pig iron (cold)	$3\frac{1}{2}$ tons	Materials charged solid
Scrap steel (sheet)	$3\frac{1}{2}$,,	
Scrap steel	$3\frac{1}{2}$,,	
Iron ore	$\frac{1}{2}$ ton	
Ferro-manganese (40 % Mn) .	300 lbs.	

Analysis of Charge at Different Periods during the Heat

Time sample taken.	C %	Si %	Mn %	P %	S %	Cu %
Average of charge	1·3	0·77	1·28	0·08	0·05	0·11
7 hours after charging	0·8	0·35	0·20	—	—	—
9 hours after charging and after addition of ores .	0·07	0·01	Trace	—	—	—
After additions of FeMn	0·18	0·04	0·30	0·08	0·05	0·11

Charge 2.—The following[2] is an average charge out of 10 consecutive heats of 0·10 per cent. carbon steel made by the Carbon Steel Co., Pittsburg.

Acid Pig and Ore Process

Materials used in charge—

Pig iron (carrying 1·4 % sand)	60,000 lbs.	Materials charged cold
Iron ore	13,500 ,,	
Recarburiser	400 ,,	
Steel produced	60,000 ,,	
Loss	400 ,, = 0·7 %	

Analysis of pig iron: C, 3·5 per cent.; Si, 1·6 per cent.
,, iron ore: Fe, 67·54 per cent.; SiO_2, 1·95 per cent.
Recarburiser—Ferro-manganese, 80 per cent. Mn.

Charge 3.—The following[3] is an average charge out of 15 consecutive heats of 0·10 per cent. carbon steel made by the Pennsylvania Steel Co., Steelton, Pa.

[1] "Stahl und Eisen," vol. xi, p. 709.
[2] "Journal American Institute of Mining Engineers," vol. 22, p. 498.
[3] *Ibid.*, p. 496.

Acid Pig and Scrap Process

Materials used in charge—

Pig iron (carrying 1·5 % sand)	11,947 lbs.	Materials charged cold
Scrap	10,660 „	
Scrap	34,893 „	
Recarburiser	300 „	
Ore	1,000 „	
Slag	4,133 „	
Steel produced	55,307 „	
Loss	2,493 „	= 4·3 %

Analysis of pig iron: C, 3·5 per cent.; Si, 2·6 per cent.; Mn, 1·11 per cent.
„ scrap: C, 0·13 per cent.; Si, 0·02 per cent.; Mn, 0·35 per cent.
„ „ C, 0·4 per cent.; Si, 0·07 per cent.; Mn, 1·00 per cent.

Sand used for repairs . . . . . 1170 lbs.

Charge 4.—The following[1] is an average charge for steel castings having the following analysis:—C, 0·24 per cent.; Si, 0·39 per cent.; Mn, 0·81 per cent.; P, 0·049 per cent.; S, 0·033 per cent.

Acid Pig and Scrap Process

Materials used in charge—

Pig iron	3000 lb.	Materials charged cold
Various kinds of scrap	9280 „	
Iron ore	300 „	
Sand	300 „	
Ferro-manganese	130 „	
Ferro-silicon	80 „	
Aluminium	2 „	

Analysis of pig iron: Si, 1 to 2 per cent.; P, 0·04 per cent.; S, 0·035 per cent.

The above charge is said to be worked off in 3½ hours. The furnace capacity is 7 tons, and it is fired with oil, the consumption of which is 50 gallons per ton of steel made.

Charge 5.—The following[2] is a charge for steel suitable for bridge construction.

Basic Pig and Scrap Process

Materials used in charge—

Pig iron	2½ tons	Materials charged cold
Bessemer rail ends	5 „	
Iron ore	500 lbs.	
Ferro-manganese (40 % Mn)	110 „	

[1] "A Modern Wisconsin Steel Foundry," "The Foundry," Nov., 1911.
[2] "Stahl und Eisen," vol. xi, p. 709.

The following table gives the analysis of the material during different periods throughout the heat:—

Time sample taken.	C %	Si %	Mn %	P %	S %	Cu %
Average analysis of charge at start	1·48	0·32	1·37	0·09	0·034	0·11
Analysis 4 hours after charging	0·82	0·01	0·37	0·06	0·030	0·11
,, 5 hours 10 minutes after charging	0·09	0·005	0·35	0·03	0·030	0·11
,, after additions of FeMn	0·15	0·009	0·53	0·04	0·023	0·11

Charge 6.—The following charge is typical of modern German works practice for steel for structural sections, angles, tees, etc.

Basic Pig and Scrap Process

Materials used in charge—

Pig iron (mixed)	11,000 lbs.	Materials charged cold
Old ingot moulds (hematite)	3,360 ,,	
Rolling mill scrap (ends of joists, channels, bars, and billets)	40,000 ,,	
Iron turnings (chips)	6,720 ,,	
Miscellaneous steel scrap, forgings, pressed tubes, etc.	19,000 ,,	
Lime	1,600 ,,	

Ferro-manganese and ferro-silicon, according to carbon required, added to ladle.

The above charge is taken from actual practice. An average of 5 heats of 33 tons each is obtained every 24 hours from fixed furnaces charged with electric charger.

Charge 7.—The following charge is typical of modern English practice for steel for wire rope billets, containing C, 0·65–0·75 per cent.; P and S, 0·025 per cent.

Basic Pig and Scrap Process

Materials used in charge—

Pig iron	22,400 lbs.	Materials charged cold
Selected steel scrap, Compressed bale hoops, Crop ends of billets	28,500 ,,	
Coal added to furnace	300 ,,	
Mill scale	2,250 ,,	
Fluorspar	340 ,,	
Lime	160 ,,	
Ferro-silicon (60 % Si)	30 ,,	Added to ladle
Ferro-manganese (80 % Mn)	59 ,,	
Aluminium	5 ,,	

Analysis of pig iron, C, 3·25 to 3·5 per cent.; Si, 2·0 to 2·5 per cent.; Mn, 1·5 to 1·8 per cent.; P, 1·0 to 1·5 per cent.; S, 0·03 per cent.

The scrap is charged after the pig iron, and not all at the same time but over a period of a few hours. Old metalliferous slag is frequently used in addition to lime in the charge.

Charge 8.—The following charge is typical of modern English practice for

best quality low carbon steel for billets containing C, 0·12 to 0·15 per cent.; Si, trace; Mn, 0·3 to 0·35 per cent.; P, 0·04 per cent.; S, 0·04 per cent.

Basic Pig and Scrap Process

Materials used in the charge—

Pig iron (mixed)	8,500 lbs.	Materials charged cold
Scrap (old hematite iron)	15,000 ,,	
Scrap (light, selected)	11,000 ,,	
Coal added to furnace	1,000 ,,	
Fluorspar	340 ,,	
Lime	130 ,,	
Silicon pig iron (12 % Si)	15 ,,	
Ferro-manganese (80 % Mn)	185 ,,	Added to ladle
Aluminium	2½ ,,	

Analysis of pig iron: C, 3·0 to 3·3 per cent.; Si, 0·8 to 2·5 per cent.; Mn, 1·5 to 2·0 per cent.; P, 1·0 to 1·75 per cent.; S, 0·025 to 0·07 per cent.

Scrap is added after the pig iron, and at intervals during the melt. Old metalliferous slag is used in the charge for fluxing.

Charge 9.—The following mild steel charge[1] shows the details of progress of the heat from time of charging until material is tapped into ladle. The finished steel contains, C, 0·15 per cent.; Mn, 0·45 per cent.; P, 0·05 per cent.; S, 0·019 per cent.

Basic Pig and Scrap Process

Time.

9.55 a.m. Commenced charging.

Pig iron	17,920 lbs.	Materials charged cold
Scrap steel	6,720 ,,	
Limestone	2,240 ,,	
Pottery mine	1,232 ,,	

11.55 a.m. Finished charging.
3.45 p.m. Melted.
4.0 p.m. Melting sample taken and 1 cwt. of calcium chloride added, followed by limestone and a little lime.
4.40 p.m. 1¾ cwts. calcium chloride, and limestone with a little pottery mine added.
5.15 p.m. Sample of metal and slag taken.
6.5 p.m. Limestone and pottery mine added.
6.30 p.m. Sample of metal and slag taken.
6.45 p.m. ¾ cwt. calcium chloride added, and one barrow of lime.
7.0 p.m. Sample of metal taken.
7.8 p.m. 4 pieces of No. 3 grey pig iron added.
7.50 p.m. Sample of metal taken. S = 0·022 per cent.
8.8 p.m. 2½ cwts. of spiegel added.
8.20 p.m. Charge tapped. 43 lbs. of 80 per cent. FeMn added to ladle.

Weight of ingots obtained	10 tons 16 cwts. 2 qrs.
,, scrap ,, ...	3 cwts.

Additions during working—

Pottery mine	19 cwts. 1 qr.
Limestone	35 ,, 0 ,,
Lime	6 ,, 0 ,,
Calcium chloride (dry)	3 ,, 2 qrs.

[1] "Journal West of Scotland Iron and Steel Institute," vol. VII, p. 121.

Average analysis of pottery mine :—

Fe_2O_3	FeO	S	Si	MnO_2	Al_2O_3	P
61·72	9·69	1·02	1·02	4·18	2·13	0·58 per cent.

The following are representative of modern basic open-hearth furnace practice in molten iron charges in part and as a whole.

Charge 10.—The following[1] is a typical charge of the Dominion Iron and Steel Co., Nova Scotia, from a 50-ton furnace producing ingot steel for rails containing C, 0·57 per cent.; Mn, 0·84 per cent.; P, 0·047 per cent.; S, 0·04 per cent.

Basic Molten Pig Iron and Scrap Process

Materials used in charge :—

Open-hearth steel castings	17,050 lbs.	Charged cold
Blooming mill crop ends	27,200 ,,	
Molten pig iron from mixer	43,900 ,,	Added about $3\frac{1}{2}$ hrs. after first scrap was charged
,, ,, ,,	30,900 ,,	
Iron ore	11,000 ,,	
Marble mountain limestone	25,300 ,,	
Routledge limestone	5,600 ,,	
Iron ore	500 ,,	Added during the heat
Fluorspar	1,500 ,,	
Ferro-manganese	1,550 ,,	Added to ladle
Ferro-silicon (50 % Si)	350 ,,	
,, (10 % Si)	300 ,,	
Coke dust	640 ,,	

Time taken, 14 hours 10 minutes.

Charge 11.—The following[2] is a typical charge of mild steel produced by the Hoesch process at the Hoesch Works, Dortmund, Germany.

Ingots contained, C, 0·08 per cent.; Si, trace; Mn, 0·47 per cent.; P, 0·04 per cent.; S, 0·067 per cent.

Basic Molten Pig Iron and Ore Process

Materials used in charge—

Lime (87·55 CaO)	4,143 lbs.	Charged before pig iron
Swedish ore (58·92% Fe)	7,582 ,,	
Rolling mill scale (76·31% Fe)	1,697 ,,	
Fluid pig iron (C, 3·28%; Si, 0·32%; Mn, 0·9%; P, 1·86%; S, 0·132%)	51,311 ,,	

In about $2\frac{1}{2}$ hours after charging, the contents of the furnace are poured into a ladle and the slag poured off. Meanwhile the following materials are charged into the furnace, after which the contents of the ladle are poured back into the furnace :—

Spathic ore (48·86 % Fe; 9·56 % Mn).
Scrap steel (99·46 % Fe).
Lime (87·55 CaO).

[1] "Canadian Mining Institute Journal," vol. X.
[2] "Iron and Coal Trades Review," vol. 80, p. 88.

During the second period of the heat, the following additions are made at different intervals:—

Rolling mill scale (76·31 % Fe)	231 lbs.
Lime (87·55 % CaO)	352 ,,
,, ,, ,, ...	453 ,,
Ferro-manganese (82 % Mn)	440 ,,

Product, 66,098 lbs. sound ingots; 792 lbs. pouring waste; 10,266 lbs. 1st slag, 9058 lbs. 2nd slag.

Total time taken during heat, 5 hours 14 minutes.

Charge 12.—The following[1] is a typical charge of mild steel produced by the molten pig iron, scrap, and ore process, in an ordinary fixed basic open-hearth furnace at the Julienhutte Works, Germany. Details of the progress of the heat, from the time of charging until tapping, are given. The finished steel contains C, 0·105 per cent.; Si, trace; Mn, 0·43 per cent.; P, 0·036 per cent.; S, 0·035 per cent.

Basic Molten Pig Iron, Scrap, and Ore Process

Time			
11.20 a.m.	Lime	2204 lbs.	Charged cold
	Krivoi-Rog ore (63 % Fe) . .	15,890 ,,	Charged cold
	Iron turnings	18,000 ,,	Charged cold
12.30 p.m.	Fluid pig iron from mixer (C, 3·61 %; Si, 1·21 %; Mn, 2·1 %; P, 0·41 %; S, 0·05 %)	70,750 ,,	
3.25 p.m.	815 lbs. lime added. Charge all melted.		
3.40 p.m.	1080 ,, ,, and 562 lbs. ore added. Charge begins to boil.		
3.55 p.m.	1234 ,, ,, ,, 750 ,, ,, Charge boils freely.		
4.10 p.m.	462 ,, ,, added.		
4.20 p.m.	374 ,, ore ,,		
4.35 p.m.	242 ,, lime ,,		
4.55 p.m.	264 ,, ,, ,,		
5.0 p.m.	363 ,, ferro-manganese added. Charge quiet.		
5.10 p.m.	Charge tapped.		

Product . . .	87,036 lbs.	sound ingots =	98·06 %
	2,138 ,,	casting waste =	2·41 %
Total yield .	89,174 ,,	=	100·47 %

Charge 13.—The following charge,[2] produced by the Talbot continuous process on November 16th, 1909, at the Cargo Fleet Works in one of the 175-ton tilting furnaces, gives the materials used and details of the progress of the heat, from the time of charging molten pig iron to the bath of low carbon steel, until the operation is completed.

[1] "Iron and Coal Trades Review," vol. 80, p. 124.
[2] "Stahl und Eisen," vol. xxx, p. 61.

Talbot Continuous Process

Time	
11.50 a.m.	120 tons low carbon steel in furnace, containing 0·16 % C; 0·019 % Mn; 0·046 % P; 0·048 % S.
12.0 a.m.	Furnace walls repaired and 8 tons of slag drawn off.
12.20 p.m.	10,072 lbs. Gellivara ore and 4695 lbs. lime charged.
12.30 p.m.	49,260 lbs. molten iron charged, containing 3·65 % C; 0·77 % Mn; 1·39 % Si; 1·66 % P; 0·044 % S.
1.0 p.m.	10,072 lbs. Gellivara ore and 4695 lbs. lime charged.
1.10 p.m.	49,260 lbs. molten iron charged, containing 0·93 % Si; 1·56 % P; 0·067 % S.
1.30 p.m.	17,910 lbs. molten iron charged, containing 0·65 % Si; 1·60 % P; 0·086 % S.
2.25 p.m.	2248 lbs. Purple ore and 2800 lbs. lime charged.
2.30 p.m.	2248 ,, Gellivara ore and 1895 lbs. lime charged.
2.45 p.m.	1895 ,, lime charged.
4.0 p.m.	1895 ,, ,, ,,
4.20 p.m.	Composition of steel—C, 0·21 %; Si, 0·036 %; Mn, —; P, 0·011 %; S, 0·032 %.

About 54 tons poured off into ladle.

Added to ladle:—Ferro-manganese (80 per cent. Mn), 848 lbs.; Ferro-silicon (50 per cent. Si), 112 lbs.; Anthracite, not given.

Composition of finished steel: C, 0·45 per cent.; Mn, 0·68 per cent.; P, 0·033 per cent.; S, 0·04 per cent.

Duration of charge between tappings, 4 hrs. 30 mins.

Charge 14.—Typical charge of rail steel from 175-ton tilting furnace (Talbot process) at the Cargo Fleet Works, September 6th, 1909.

Talbot Continuous Process

Materials charged:—

Molten pig iron added to bath of liquid low carbon steel in two stages	123,160 lbs.
Iron ore	31,350 ,,
Rolling mill scale	2,573 ,,
Lime	20,153 ,,
Dross	6,490 ,,
Ferro-manganese (80 % Mn)	1,120 ,,
Ferro silicon (50 % Si)	167 ,,

Total yield of ingots, 128,310 lbs.

Analysis of pig iron: Si, 1·15 per cent.; Mn, 0·63 per cent.; P, 1·60 per cent.; S, 0·122 per cent.

Analysis of finished steel: C, 0·59 per cent.; Mn, 0·70 per cent.; P, 0·044 per cent.; S, 0·063 per cent.

Charge 15.—Typical charge of constructional steel from 175-ton tilting furnace (Talbot process) at the Cargo Fleet Works, September 7th, 1909.

Talbot Continuous Process

Materials charged :—

Molten pig iron added to bath of liquid low carbon steel in two stages	111,963 lbs.
Scrap steel	22,392 ,,
Iron ore	30,220 ,,
Rolling mill scale	5,149 ,,
Lime	17,914 ,,
Dross	6,489 ,,
Ferro-manganese (80 % Mn)	840 ,,
Ferro-silicon (50 % Si)	171 ,,

Total yield of ingots, 120,210 lbs.

Analysis of pig iron : Si, 1·09 per cent. ; Mn, 0·69 per cent. ; P, 1·83 per cent. ; S, 0·107 per cent.

Analysis of finished steel : C, 0·185 per cent. ; Mn, 0·66 per cent. ; P, 0·03 per cent. ; S, 0·058 per cent.

CHAPTER XXXVII

THE DUPLEX PROCESSES

THE name "duplex" was given to the dual operations of partially converting iron to steel in the Bessemer converter, and finishing the conversion in the open-hearth furnace. The process was conducted first in Witkowitz, Bohemia, in 1878, and is carried out with success in countries where the materials cannot be more economically converted to steel by the Bessemer or open-hearth processes independently.

While in Germany the Hoesch or Bertrand-Thiel process has superseded almost entirely the duplex process, yet in America large plants have been installed quite recently where the Bessemer converter and open-hearth furnace are working in conjunction with each other.

Converter and Open-hearth Furnaces.—In Fig. 218 is illustrated[1] the arrangement of converters and mixers installed in 1911 at the Saucon Steel Works of the Bethlehem Steel Co., Pa., U.S.A. This is perhaps one of the largest duplex plants, having all the latest improvements for handling the materials from the blast furnaces until the finished steel is in the casting ladle.

The blast furnaces from which the metal is conveyed to the steel works are about 1½ miles distant. The metal is conveyed in double-trunnion ladle trucks of 23, 35, and 40 tons capacity, and taken direct to the mixers, which have a capacity of 400 tons each. Outside the mixer building the metal is weighed on a 100-ton track weighbridge, and then pushed into the building, where the ladle is lifted by an overhead crane of 60 tons lifting power, the metal being poured into the mixer by a 20-ton auxiliary crane. The metal is conveyed to the converters in 25-ton ladle trucks, which are drawn along the platform on a railway track by means of a motor-driven rope haulage system, controlled by the man on the mixer platform. The distance from the mixer to the farthest converter is 145 feet. The converters have each a capacity of 20 tons. The position of the open-hearth furnaces in relation to the converters is shown in Fig. 219. The metal is conveyed to the open-hearth furnaces in ladle trucks, and afterwards handled and finished in the ordinary manner.

Other plants have been installed recently, but notably the duplex process plant at the Tenessee Iron, Coal, and Railroad Co., U.S.A.

Open-hearth Furnaces and Electric Furnaces.—In several works in different countries the electric furnace is used in conjunction with the open-hearth furnace. The plant consists of a fully equipped modern open-hearth furnace (fixed or tilting), from which the semi-refined charge is tapped and poured into and refined in the electric furnace. The metal is generally taken from the open-hearth furnace in a ladle suspended from an overhead crane, and tipped into the electric furnace by an auxiliary crane. The refined charge is poured or tapped from the electric furnace into a ladle suspended by the same crane, and afterwards taken to the moulds and cast in the ordinary manner. The size and number of open-hearth furnaces necessary to work in conjunction with an electric

[1] "Iron Age," 1911, p. 784.

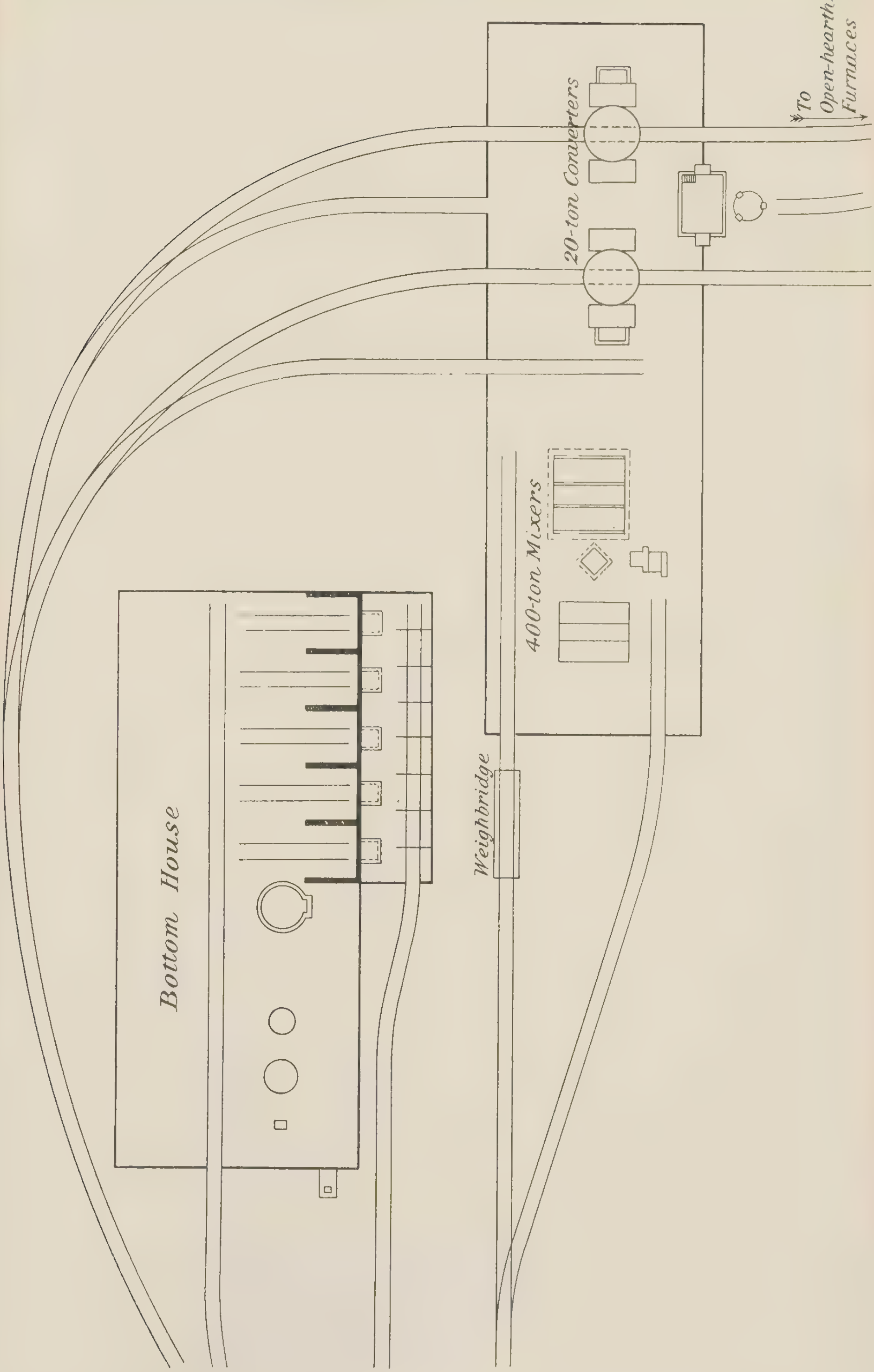


FIG. 218.—Converter Plant at the Saucon Steel Works of the Bethlehem Steel Co., working in conjunction with Open-hearth Furnaces.

furnace depends upon the durations of the operations in each furnace. If, for instance, the refining in the electric furnace takes an average time of 1 hour per heat, and the capacity of the furnace is 5 tons, two 50-ton tilting furnaces working on the continuous melting principle would be necessary to keep one electric furnace going constantly, that is, tapping 5 tons every 1 to 1½ hours from each tilting furnace alternately.

Steel is also refined in electric furnaces, after being partially converted in the Bessemer converter. The arrangement of converters and electric furnaces is similar to that of the open-hearth and electric furnaces, the Bessemer converters being placed in the position occupied by the open-hearth furnaces.

Triplex Steel Process.—The name "Triplex" has been given to an arrangement of furnaces in which the manufacture of steel from molten iron is conducted in 3 stages. One method adopted is to take the metal from the blast furnaces and partially refine it in an acid open-hearth furnace, then in a basic Bessemer converter, and, lastly, in a tilting open-hearth basic furnace. If, however, all the operations of refining are considered in the ordinary molten processes, including (1) that which goes on in the ladle during transit from the blast furnace to the mixer, (2) in the mixer, and (3) in the subsequent furnaces, the name "multi-process" would have to be applied.

In view of the variety of methods of manufacture, it is necessary to consider carefully all the conditions affecting the particular kind of manufacture it is intended to undertake before deciding upon any particular design and arrangement of steel works.

Materials used in the Duplex Processes.

The materials used for steel manufacture in the Duplex processes are such that it is usually found more advantageous to remove part of the impurities in one furnace, lined with say acid refractory material, and to complete the removal of impurities and finish the steel in another furnace having a lining of basic material. By manufacturing in this manner, it has been possible to use highly phosphoric pig iron with too much silicon to enable it to be successfully converted to steel in either the acid or basic lined converter, or open-hearth furnaces independently.

Various combinations of furnaces have been tried with many varieties of pig irons, and to give some slight indication only of the numerous charges which have been employed, the following details are set forth.

Duplex Process. Bessemer and Open-Hearth.

Charge I. At Witkowitz, about 6 heats of steel are obtained from each open-hearth furnace per day. Taking the average charges of molten metal for the year 1908–9,[1] the following materials were used in the combined furnaces :—

Pig iron	87·12 %
Loss	12·88 %
Iron ore	2·7 %
Lime	7·8 %
Coal	10·5 %
Dolomite (calcined)	2·67 %
Magnesite (sintered)	0·31 %
Pouring waste	2·11 %
Open-hearth slag	10·39 %
Ingots produced	89·25 %

Average weight of charge, 19·9 tons.

[1] "Iron and Coal Trades Review," vol. 80, p. 88.

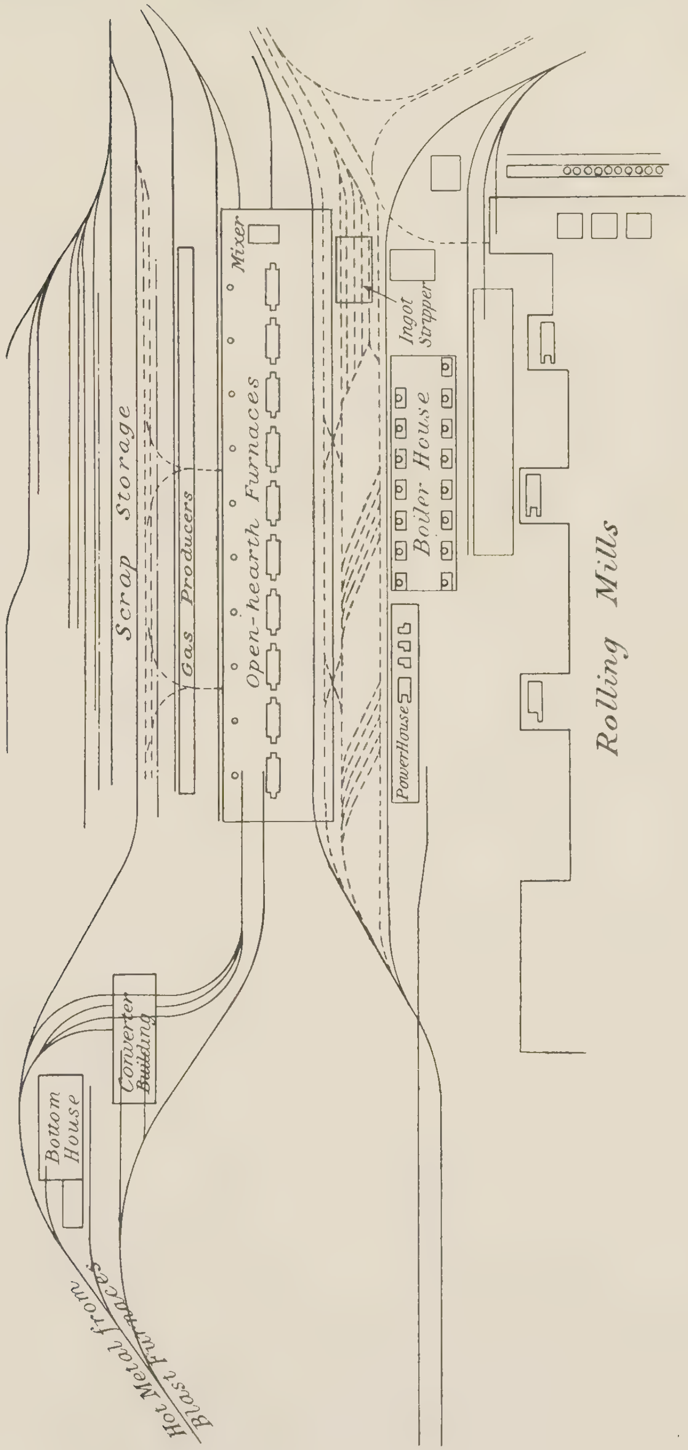


FIG. 219.—Plan of the Steel Plant at the Saucon Works of the Bethlehem Steel Co., U.S.A.

Duplex Process. Bessemer and Electric.

Charge II.—The following is a typical charge[1] of blown basic Bessemer metal, refined in a nominal 8-ton Röchling-Rodenhauser furnace at Völklingen, Germany.

Charge . . . . 5 tons

Period	Time hrs.	Time mins.		Sample.	C	Si	Mn	P	S
					Percentages.				
Oxidation period.	0	0	Molten charge	1	0·06	0·02	0·49	0·06	0·c65
Oxidation period.	0	20		2	0·07	0·02	0·28	0·025	0·054
Oxidation period.	0	40		3	0·07	0 02	0·21	0·022	0·049
Oxidation period.	1	0		4	0·06	0·03	0·12	0·018	0·053
Oxidation period.	1	20		5	0·06	0·03	0·12	0·015	0·057
Oxidation period.	1	40		6	0·07	0·02	0·12	0·0145	0·053
Slagging off, recarburising, and formation of second slag.	2	0	Added 220 lbs. coke. ,, 28·4 ,, ferro-silicon	7	0·06	0·02	0·12	0·012	0·048
Slagging off, recarburising, and formation of second slag.	2	40	,, 13·2 ,, ferro-spiegel ,, 28·4 ,, 50% ferro-silicon to slag	8	1·26	0·02	0·15	0·015	0·028
Reduction period.	2	50	Added 4·4 lbs. of 80% ferro-manganese						
Reduction period.	3	0	Added 15·4 lbs. of 50% ferro-silicon to slag	9	1·39	0·15	0·21	0·016	0·022
Reduction period.	3	15		10	1·30	0·21	0·24	0·013	trace

Duration of heat . . . . . . 3 hrs. 15 mins.

Throughout heat, 770 lbs. of lime were added, and throughout the oxidation period, 198 lbs. of W. S.

Duplex Process. Bessemer and Electric.

Charge III.—The following[2] is a typical charge of blown Bessemer metal refined in a 15-ton Héroult furnace at the Illinois Steel Co., South Chicago, U.S.A. The metal is slightly overblown in a 15-ton acid converter, and is poured into the electric furnace. At the same time, iron oxide and lime is shovelled in through the working doors to produce a basic slag.

Materials charged :—

	lbs.
Blown Bessemer metal	30,000
Scale	700
Lime—first slag	600
Lime—second slag	600
Recarboniser	130
Fluorspar	400
Coke dust	200
Ferro-Manganese (80% Mn)	200
Ferro-Silicon (10% Si)	60
,, (50% Si)	80

For repairing the furnace between the heats, 400 lbs. of dolomite and 25 lbs. of magnesite were used.

[1] "Journal Iron and Steel Institute," 1909, I, p. 312.
[2] "Iron and Coal Trades Review," 1911, p. 210.

Duplex Process. Open-Hearth and Electric.

Charge IV.—The following[1] is a typical charge of molten metal from a 25-ton open-hearth furnace refined in a 3-ton Girod furnace at Gutehoffnungshütte.

Weight of charge . . . . 7053 lbs.

	Sample No.	Percentages. C	Si	Mn	P	S
Oxidation period :—						
Charge 7053 lbs. molten metal . .	1	0·15	tr.	0·54	0·034	0·054
After adding 22 lbs. ore	2	0·14	,,	0·40	0·021	0·048
,, ,, 33 lbs. ,, ...	3	0·14	,,	0·34	0·016	0·044
,, ,, 55 lbs. ,, ...						
Just before slagging	4	0·10	,,	0·29	0·008	0·046
Deoxidation period :—						
After adding 52½ lbs. petroleum coke and 110 lbs. refining slag .	5	0·50	,,	0·26	0·01	0·034
After adding 88 lbs. refining slag .	6	0·50	,,	0·26	0·01	0·038
,, ,, 66 lbs. ,, ,, .	7	0·49	,,	0·27	0·01	0·026
,, ,, 19¾ lbs. FeMn ,, .	8	0·50	,,	0·49	0·011	0·026
,, ,, 2½ lbs. powdered petroleum coke and 11 lbs. FeSi .	9	0·52	0·07	0·52	0·015	0·026
,, ,, 11 lbs. ferro-silicon .	10	0·52	0·14	0·52	0·012	0·018
,, ,, 8¾ lbs. ferro-manganese	11	0·56	0·14	0·61	0·015	0·01
Final sample	12	0·56	0·14	0·62	0·015	0·01

Weight of steel produced, 6942 lbs.

[1] Paper by Dr. A. Mueller, "Stahl und Eisen," Aug. 3rd, 1911.

PART IV

THE ELECTRIC PROCESS

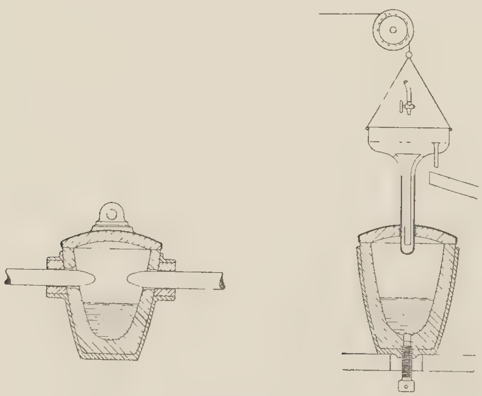
CHAPTER XXXVIII

THE EVOLUTION OF THE ELECTRIC FURNACE

PROBABLY no other form of steel-making furnace has received so much attention by Engineers and Metallurgists during a similar period as the electric furnace. Although its earliest application dates no further back than 1879, it would be a laborious task to furnish a description of all the types of furnaces which have been designed since then. Electric furnaces of different types have been used during recent years for the manufacture and refining of steel, and there is sufficient evidence from the commercial results obtained, that in the future a more general application of the electric furnace in steel works will depend upon the following considerations :—

1. Simplicity of design of furnace.
2. Applicability of design to the metallurgical operations involved.
3. Efficient working and economical consumption of electricity.
4. Low cost.
5. Minimum of repairs and adaptability to continuous working.

Historical. The Siemens Furnace.—The first electric furnace used for the production of steel was an experimental one designed by the late Sir Wm. Siemens in 1879. In his patent of that date, two types of furnaces are shown, as illustrated in Fig. 220. The furnace shown in Fig. 220 *a*, consists of a crucible in which is placed the material to be melted, the heat being obtained by radiation from two electrodes placed horizontally above the charge. The eloctrodes, which, it is stated, may be either carbon or water-cooled tubes, are fed forward by means of friction rollers which are operated by a sand wheel and worm gear, actuated by a solenoid.



a. *b.*

FIG. 220.—Siemens' Experimental Arc Electric Furnace.

In a modified design of the furnace, shown in Fig. 220 *b*, the current is led to the furnace by an electrode suspended over the charge in the crucible, and, arcing across the air gap, passes through the material, and out by

means of an electrode fixed into the bottom of the crucible, and in contact with the charge. In a furnace of this design, Siemens was able to melt 22 lbs. of iron or steel in one hour, and based upon these experiments he worked out the cost of production of steel by electricity, and concluded that it could be made as economically by the electric furnace as by the open-hearth furnace. These experiments, however, were not developed commercially, and for eight years little was done in promoting this new method of steel manufacture.

The Ferranti Furnace.—In 1887, Mr. S. de Ferranti introduced a distinct type of electric furnace, two views of which are shown in Fig. 221. The arrangement consists of a rectangular annular crucible (provided with a cover), in which are placed the materials to be melted. Through the open space in the centre of the crucible and on either side, pass pole pieces constructed of a number of thin soft iron plates. An insulated coil is wound round the inner pole piece. The whole arrangement is fixed on a cast iron frame mounted on trunnions, the magnet being insulated from the frame. Heat is induced by the

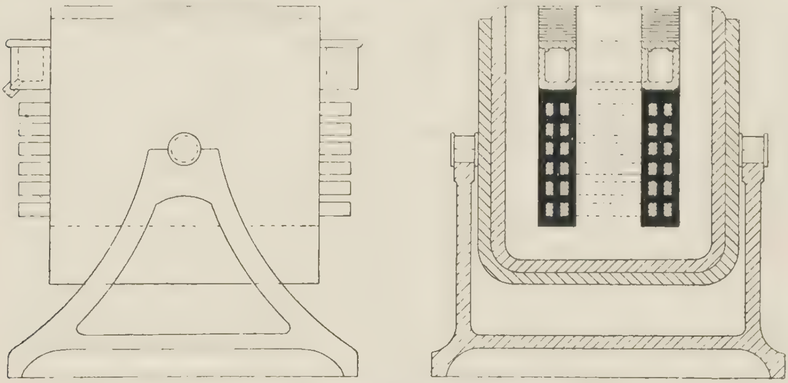


FIG. 221.—Ferranti's Electric Furnace.

current passing through the coil surrounding the iron magnet. The whole apparatus forms an electric transformer, in which the primary coil induces current in the annular chamber taking the place of a secondary winding.

Apparently, development of this type of furnace was dropped, for no commercial success is recorded of its operation. The same principal of melting by induced currents was patented by Colby in the U.S.A. in 1890, although his arrangement differed slightly from Ferranti's.

The Stassano Furnace.—It was not until the year 1898 that the electrical production of steel was again taken up actively. In this year, Major Stassano constructed a furnace at Rome, on the arc principle, with the object of smelting iron ores and producing steel direct in the one operation. His furnace resembled a charcoal blast furnace with the tuyeres replaced by carbon electrodes, and the ore, as it passed down the furnace, was fused by the electric arc formed between the points of the electrodes. This furnace was not a commercial success, and was abandoned in favour of a furnace in which the materials were charged upon a hearth, and melted by the radiation of heat from arcs formed between electrodes situated just above the materials. In this design of furnace, Stassano was able to reduce ore when briquetted with charcoal and melted with suitable fluxes, a good quality of steel being produced. He, however, found the furnace more particularly adapted for the production of steel from scrap, and on these lines he advanced.

The Héroult Furnace.—While Stassano was pursuing his investigations, Mr. P. Héroult (now Dr. Héroult), was engaged in the U.S.A. on the production of aluminium in the electric furnace, and in 1899 his attention was turned to the manufacture of steel by the same means. The furnace with which he experimented consisted of a hearth containing the materials, over which were suspended two carbon electrodes. The current, passing down one of these electrodes, formed an arc in the air-gap between the end of the electrode and the material on the hearth. Similarly, after passing through the metal bath, it formed another arc between the metal and the end of the other electrode on its way to the negative terminal of the supply generator. The heating effect of these two arcs was utilized to melt the metal in the hearth, which on becoming molten, was tapped out into moulds.

The Kjellin Furnace.—A year after Héroult's first experiments, Mr. F. Kjellin (the late Dr. Kjellin), in 1900, introduced a furnace of the induction type, similar to that patented by Ferranti in 1887. With this furnace he carried out investigations with the object of producing steel from iron ore briquettes, pig-iron, and steel scrap, and as a result he was able to make high-grade tool steel commercially in 1902.

Modern Developments.—It will be observed from the foregoing that the inventions and experiments of Stassano, Héroult, and Kjellin, embodied the principles of the earlier patents of Siemens and Ferranti. Stassano's furnace was an application of the design introduced by Siemens, *vide* Fig. 220 *a*, p. 418. Héroult's furnace showed originality in that the current left the furnace through a second electrode above the metal, instead of through a second electrode at the bottom after passing through the metal in the furnace. Kjellin's furnace was an application of Ferranti's principle of heating by an induced current due to the resistance set up by the metal bath to the current.

These three furnaces are the types upon which practically all the developments of late years have been based. The designs of some furnaces have embodied slightly different arrangements with the object of producing more efficient and simpler working, while others have been but the combination of two or more types.

The Girod furnace is an application of Siemens' original furnace with the bottom electrode. The Rochling-Rödenhauser furnace is a development of the Kjellin furnace, the heating being effected by induction and by the resistance set up by plates built into the furnace lining. Other types of furnaces, less known than the foregoing, are being developed, and some of them are described and illustrated in the following chapters.

CHAPTER XXXIX

ARC FURNACES

Introduction.—The first electric furnace used for the manufacture of steel, was an arc furnace, invented by the late Sir William Siemens. It is notable that the first furnace to be used commercially was also an arc furnace, introduced by Major Stassano in Italy in 1898. This furnace, moreover, is the only one which has retained the principle of heating purely by radiation from an arc or arcs formed between carbon electrodes situated above the metal in the hearth of a furnace.

The Stassano Furnace.—Stassano's earliest experiments were not very successful in producing steel direct from iron ore on a commercial scale. These

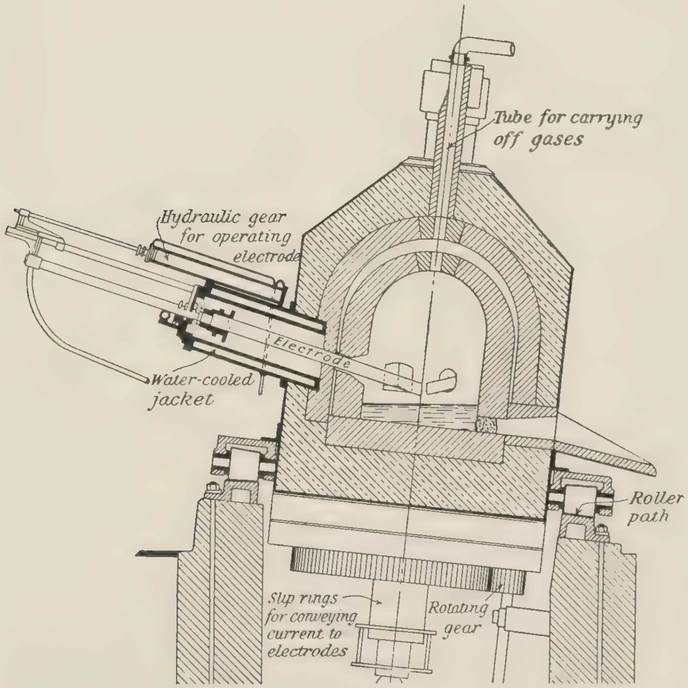


FIG. 222.—The Stassano Furnace.

were conducted in a furnace closely resembling a small blast furnace, but with tuyeres replaced by carbon electrodes. When, however, he adopted the hearth type of furnace, his experiments were more successful.

Originally, the furnace was of the fixed type, but it was found that the metal bath was not sufficiently stirred up to ensure refining and perfect homogeneity, and the rotary type of furnace was therefore adopted. A sectional elevation of this latter type is shown in Fig. 222.

Description of the Furnace.—The furnace consists of a cylindrical shell built up of steel plates, mounted on a roller path so that the furnace itself is inclined at an angle of about 7° to the vertical. The furnace is rotated by means of gearing, driven by a motor. The shell is lined with magnesite blocks. The carbon electrodes pass through the furnace lining nearly horizontally, and are enclosed in water-cooled jackets, bolted to the shell, which guide and support the electrodes, the inner ends of which point towards the centre of the furnace. The adjustment of the electrodes is obtained by means of small hydraulic rams. The current is conveyed to the electrodes by cables which pass through the pivot, and are connected to brushes which make contact with slip-rings below the base of the furnace, from which the flexible cable to each electrode is attached. Since the whole of the furnace rotates, the hydraulic supply for cooling and actuating the electrodes, also passes up through the pivot.

The furnace is usually worked on three-phase current, three electrodes being used, but in the case of large furnaces, six electrodes are employed—two to each phase. The electrodes used are considerably smaller in cross section than those employed in furnaces of the Héroult type.

The Stassano furnace has been designed with two objects, viz.—

(*a*) For producing steel direct from the ore.

(*b*) For melting and refining mild steel scrap or pig iron.

Production of Steel direct from the Ore.—When working the furnace for the production of steel from the ore, the top of the furnace connects with a tube, through which the products of combustion are carried off. The ore used is first crushed and ground, then mixed with fluxes and carbon and made into briquettes. The proportion of carbon used is governed by the composition of the ore employed, the latter being carefully analysed so that its reduction can be fully ensured by the carbon. By regulating the quantity of the carbon, different grades of steel can be produced, varying from very low to high carbon steels, or pig iron.

In a paper by Mr. R. Catani,[1] the following particulars are given of the results of experiments made by Stassano for the direct production of steel from the ore: In the first experiments, hematite ore of good quality was used, containing 93·02 per cent. of Fe_2O_3, briquetted with pitch and charged into the furnace with charcoal and limestone. In the second set of experiments a different ore containing 68·7 per cent. of Fe_2O_3 was used. This was crushed and briquetted with a 25 per cent. solution of silicate of soda instead of pitch. Steel of good quality was produced, but apparently only four experimental charges of 220 lbs. each were made.

The process described above does not appear to have been followed to any large extent, the furnace having been chiefly employed in the production of steel from mild steel scrap.

Production of Steel from Scrap.—The following particulars[2] of the working of a 1-ton furnace (300 h.p.), producing steel for castings in Germany, will indicate the methods adopted for the operation of the Stassano furnace, when used for melting and refining mild-steel scrap.

The furnace has three electrodes, each adjusted by hydraulic rams, and water-cooled. A 5-h.p. motor is used for rotating the furnace. The material charged is good steel scrap containing 0·2 to 0·3 per cent. C; 0·3 to 0·5 per cent.

[1] "Journal Iron and Steel Institute," 1911, II, p. 215.

[2] "Foundry Trade Journal," 1909, p. 19.

Mn; 0·07 to 0·09 per cent. Si; 0·03 to 0·15 per cent. S; 0·08 to 0·12 per cent. P. When starting off the furnace, the lining is first thoroughly dried. The electrodes are then brought together, the arcs formed, and the furnace brought to a high temperature, ready for the reception of the charge. The electrodes are now drawn back, about two-thirds of the charge is put in, the carbons are pushed forward, and the current switched on.

The voltage of the supply is 105 to 110, and the current is regulated at 1000 to 1100 amps.

A little iron ore or mill scale with lime is added to the initial charge in order to refine and dephosphorise it. The first slag is withdrawn before the charge is completely melted, and when the bath is molten the remainder of the charge is introduced as rapidly as possible without turning off the current. When the whole charge is melted (which takes about 3½ hours), the second slag is run off, and more scale and lime added if necessary. This third slag is removed and a final slag formed by the addition of a small quantity of lime and ferro-silicon, which completes the refining. At the end of about fifteen minutes ferro-manganese is added, and about seven minutes later the charge is tapped. The addition of a small quantity of aluminium is made in the ladle. High-carbon steel is obtained by the addition of Swedish pig iron just before tapping.

A 1-ton charge requires a power consumption of 800 to 1000 k.w. hours, according to the purity of the materials used and the degree of refining necessary. An average value of 900 k.w. hours may be taken. In addition to this, the furnace must be kept hot while it is out of use during the run. This is done by passing current through intermittently as required.

The finished product for low-carbon steel is as follows:—

C	0·08 to 0·18 %
Si	0·08 to 0·10 %
Mn	0·4 %
P	0·06 %
S	0·03 %

Output and Cost of Plant.—The cost of a 1-ton furnace, together with switchboard, foundations, etc., is about £1750. From this furnace three to four 1-ton charges can be obtained per day of 24 hours, so that running the furnace for 240 days per year, at an average output of 3½ charges per day, the annual output = 840 tons.

		£	s.	d.
Annual charge for depreciation @ 10 %	=	175	0	0
Annual charge for interest @ 5 %	=	87	10	0

∴ Total annual charge for depreciation and interest = £262 10

Charge for depreciation and interest per ton of liquid steel

$$= \frac{£262\ 10s.\ 0d. \times 20}{840} = 6s.\ 3d.$$

Working Costs (per Ton of Liquid Steel for Carbon Steel Castings)

Cost of Repairs.—The magnesite lining costs £20 to replace, and lasts about three weeks. The repair of the lining takes from 4 to 6 days, consequently the number of working days per year is low, *i.e.* 240 as given above. The cost of repair materials, wages, and sundries, is given as 11*s.* per ton of liquid steel.

Cost of Power and Cooling Water.—Taking the power consumption at 900 k.w. hours per ton for melting and refining, the power cost @ 0·3*d.* per unit = £1 2*s.* 6*d.* per ton of liquid steel. In addition to this, an allowance of 108 units is made for heating up the furnace during intervals, *i.e.* an additional cost per ton of 2*s.* 8½*d.* For cooling the electrodes about 440 gallons of water are used per hour, which at 2*d.* per 1000 gallons = 5*d.* per ton of steel.

∴ Total cost of power and water = £1 5*s.* 7½*d.* per ton of liquid steel.

Cost of Electrodes.—The life of the electrodes is 9 charges, and each costs 4*s.*, *i.e.* 12*s.* per set of three. The cost of electrodes per ton of steel is therefore $\frac{12}{9}$ = 1*s.* 4*d.*, but these carbons, being nearly horizontal, are very often broken during the charging operation and in working, and it has been found that a safer cost is 2*s.* 6*d.* per ton of steel.

Cost of Labour.—A 1-ton furnace requires three men per shift, and in Germany, where this furnace is in operation, the wages for the day and night shift amount to 30*s.*, or $\frac{30}{3\cdot5}$ = 8*s.* 8*d.* per ton of steel produced.

Cost of Raw Materials.—Taking the figures given for a typical charge, the materials used per ton of steel, in addition to the scrap, are as follows :—

	s.	*d.*
44 lbs. of hammer scale @ 17*s.* ton	0	4
44 lbs. of lime @ 12*s.* ton	0	3
17½ lbs. of ferro-silicon (12 %) @ 150*s.* ton	1	2
9 lbs. of ferro-manganese (80 %) @ 220*s.* ton	0	11
1½ lbs. of aluminium	1	2
Total cost of fluxes and ferro additions	3	10

Summary of Costs

Cost of plant, £1750.

	£	*s.*	*d.*
Depreciation and interest	0	6	3
Repairs	0	11	0
Power and cooling water	1	5	7½
Electrodes	0	2	6
Labour	0	8	8
Raw materials—Steel scrap	3	7	0
Fluxes and ferro-additions	0	3	10
Management (50 % of cost of labour)	0	4	4
Royalty—not included		—	
Cost per ton of liquid steel	£6	9	2½

CHAPTER XL

INDUCTION FURNACES

THE characteristic feature of the furnaces described in this chapter is that of heating by induced currents. The furnaces are transformers, the current being induced in the bath of metal, which takes the place of the secondary winding. The first induction furnace was patented by Mr. S. de Ferranti in 1887, but not until 1900 was the principle put into commercial use, when the late Dr. Kjellin introduced his furnace in Gysinge, Sweden. Several modified designs have been brought forward, some of the more important of which are included in the following pages.

THE KJELLIN FURNACE

The first Kjellin furnace was designed for a charge of 176 lbs. and required 78 kilowatts, giving an output of about 600 lbs. in 24 hours at an average power consumption of over 7000 kilowatt hours per ton of steel. This was gradually improved until the furnace produced, with 58 kilowatts, 1300 to 1550 lbs. of steel ingots in 24 hours. The charges were about 220 lbs. each, and the time between teemings from 3 to 4 hours. The furnace was lined with silica bricks, which required renewing about once a week. The results of this furnace were encouraging (although not satisfactory from a commercial point of view), and in 1902 a furnace was started up having an output of about 4 tons in 24 hours, taking 225 kilowatts and producing about 1 ton every tapping. This furnace was lined with magnesite, as it was found that the charge in the small furnace took up a high percentage of silicon from the lining. (The magnesite lining had a very much longer life, the first lining lasting 12 weeks.)

Description of the Furnace.—The arrangement of the Kjellin furnace is seen from Fig. 223, which illustrates one of the stationary type. Fig. 224 shows diagrammatically the electric circuits for the furnace. In principle the furnace is a transformer in which the circular trough takes the place of a single short-circuited secondary winding, the trough forming the melting bath of the furnace. The trough is closed with covers, and the central space within the ring is occupied by a core composed of soft iron plates. The core is surrounded by a copper wire coil insulated with asbestos, connected to an alternating current generator. The current passing through the coil excites a varying magnetic flux in the iron core, and the variation in the flux induces a current in the closed circuit formed by the molten metal in the trough. The ratio between the primary and secondary current is determined by the number of turns of the primary, and the magnitude of the current in the molten metal is therefore practically given by the product of the primary current and the number of turns of the primary coil. Thus, in a small furnace of this type, a current of 500 volts and 280 amperes supplied to the coil, induces a current of 7 volts and 20,000 amperes in the bath.

The Kjellin furnace is in reality a large crucible electrically heated, and the

quality of steel produced is governed by the quality of the raw materials used, since little or no refining is done in the bath.

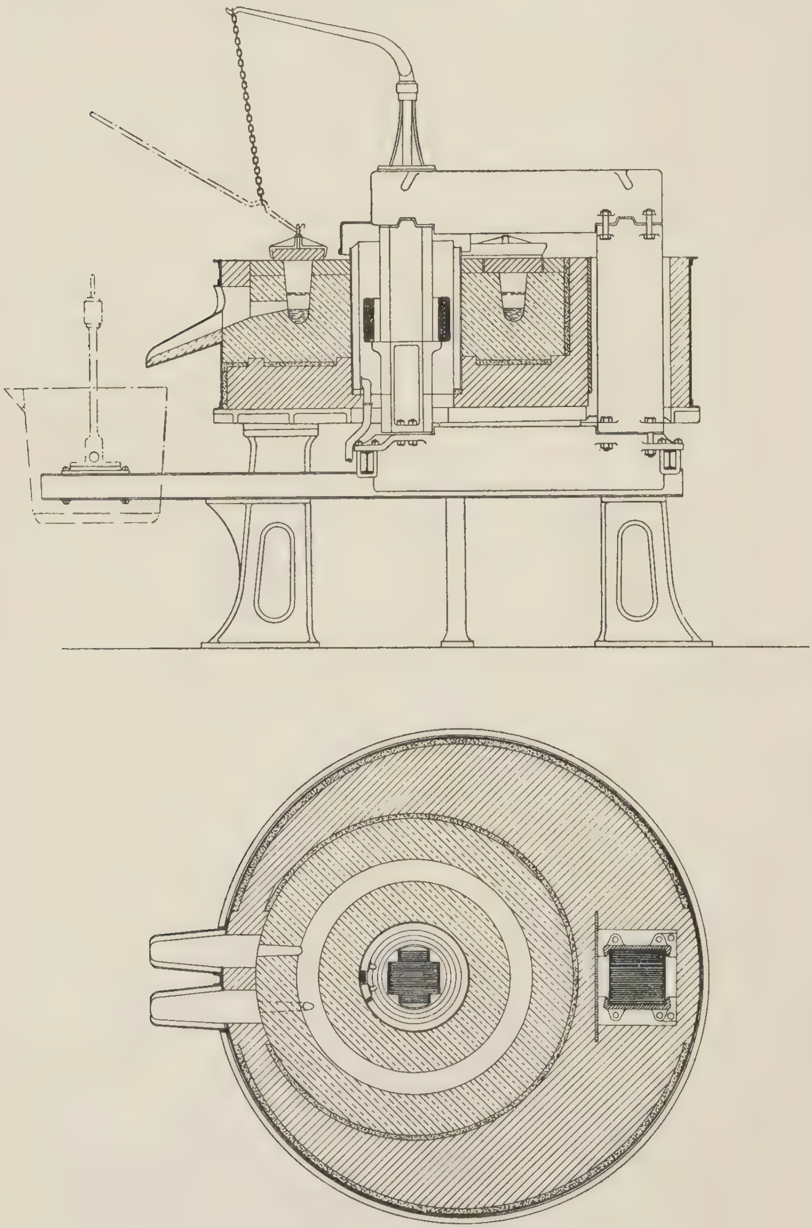


FIG. 223.—The Kjellin Furnace.

Operation of the Furnace.—When starting the furnace, it is not possible to fill the trough with broken pieces of pig iron or scrap and melt them down,

since the voltage of the induced current is too low to produce arcs sufficient to bridge the gaps between the pieces in the charge. Instead, an iron ring must be placed in the trough and melted down to form the bath, or the trough must be filled with metal already molten. When working continuously, the custom is to leave a sufficient amount of metal in the trough, after tapping out the charge, to provide a complete circuit in the trough before introducing the next charge.

The furnace is charged at the commencement of a heat with a portion of the materials, and as this melts, the remainder is added from time to time. The carbon and silicon are adjusted by selecting materials which will produce the desired steel, and by means of suitable additions, special steels of almost any composition can be made. Typical charges of materials used and data regarding the working of the furnace are given in Chapter XLV on "Materials Used in the Electric Process."

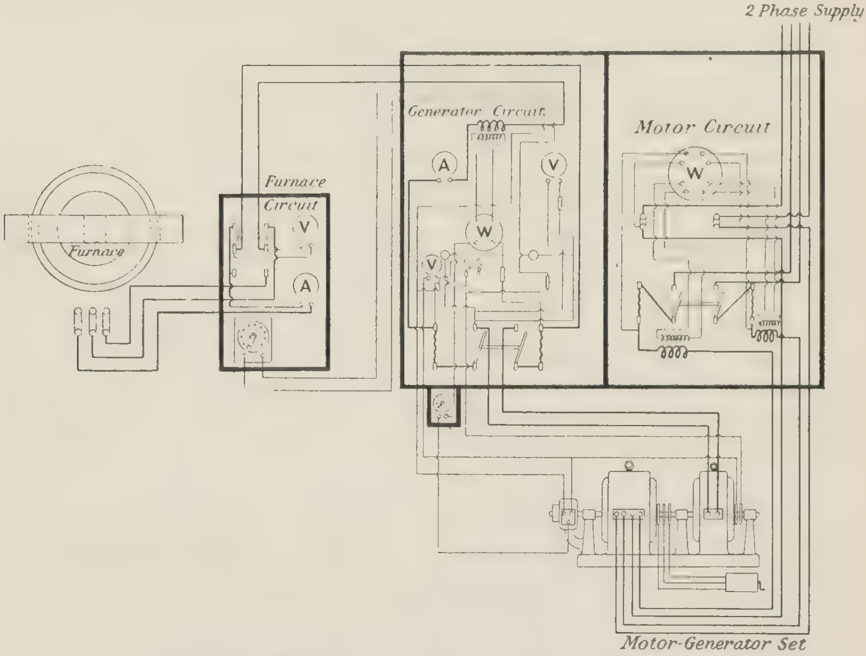


FIG. 224.—Diagram of Electric Circuits for Kjellin Furnace.

Working Data and Costs.—Since the Kjellin furnace is more particularly adapted for the production of high-grade steel from pure materials, the cost of raw materials is by far the most important factor in the total cost of steel produced. The process can be compared with the crucible process, with electric power taking the place of coke or gas. General data relating to the working of the furnace are given below.

Output of furnace: A 165–170 k.w. furnace making high grade tool steel will produce about 4 heats of 1 ton each per 24 hours.

Cost of repairs: The cost of upkeep of the lining of a 1-ton furnace is about 2*s.* 6*d.* per ton of steel produced.

Power: When producing tool steel from good quality pig iron and steel scrap, a consumption of about 800 k.w. hours is required per ton of steel. Assuming, therefore, that power can be purchased at 0·3*d.* per k.w. hour, the cost per ton of steel = £1 0*s.* 0*d.*

Labour: 3 men are required to work a 1-ton furnace.

Loss of material in melting: The loss in melting a charge of good quality raw materials is about 2 per cent.

The Röchling-Rodenhauser Electric Furnace

In the original Kjellin furnace difficulty is experienced with material which has to be refined and treated in large quantities. For instance, when a charge of three tons or more is to be dealt with, the section of the bath becomes very large, causing a low resistance and consequently lowering the power factor, necessitating the use of a generator of low frequency. The processes of desulphurisation and dephosphorisation are also very tedious in the Kjellin furnace, as it is difficult to keep the slag sufficiently fluid for such purposes. To overcome these difficulties, Dr. Rodenhauser and Dr. Schonawa, of the Röchling'sche Iron and Steel Works at Volklinger, Germany, modified the Kjellin furnace, the improved furnace being known as the "Röchling-Rodenhauser."

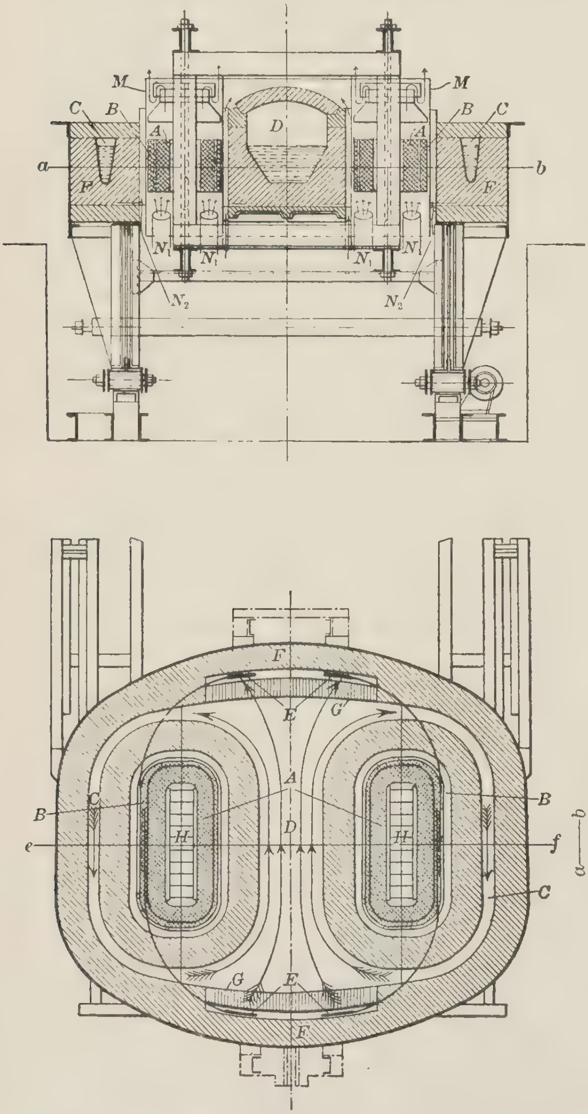


Fig. 225.—Röchling-Rodenhauser Single-phase Furnace.

Description of the Furnace.—The furnace is made for single, two, or three-phase currents, and consists of a transformer furnace after the principle of the Kjellin type, but with two ring-shaped baths adjacent to, and communicating with one another in the case of a single-phase furnace, and with three baths in the case of a three-phase furnace. Fig. 225 gives two views of a single-phase furnace. The junction of the ring-shaped baths is in the form of a square or rectangular hearth, with doors in front and behind.

The principal feature is a heavy secondary winding of copper cables, placed around and co-axial with the primary (one on each leg of the core), surrounded by the rings forming the charge. These copper secondaries, consisting of a few turns only, are connected to conductive plates built into the furnace wall. These plates are of corrugated cast steel, and coated with a compound of magnesite, dolomite, and tar. Although bad conductors when cold, the plates act as fairly good conductors when the furnace is charged with molten metal, and readily allow the current to pass. By this means, about 70 per cent. of the current is transmitted to the bath by induction in the ring-shaped baths, and the remainder through the side plates. The copper secondary is placed close to the primary, to keep the power factor as high as possible.

The ring-shaped part of the bath is covered with bricks at a height below the level of the charge in the centre bath, so that no slag can enter into the ring baths. These rings require comparatively small repairs during a long run, and the rectangular bath in the middle is readily accessible and can be easily patched. The lining is calcined magnesite or dolomite, mixed with tar and stamped into position hot. Fig. 226 shows a three-phase furnace which, although still used, is being superseded by single and two-phase furnaces.

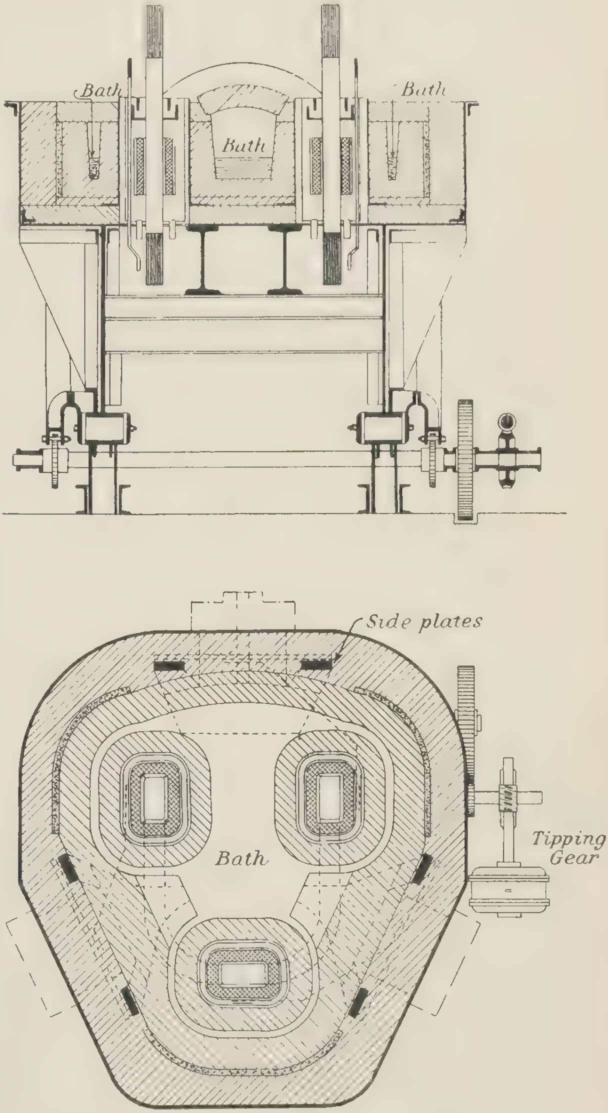


FIG. 226.—Röchling-Rodenhauser Three-phase Furnace.

Operation of the Furnace.—After the lining is stamped in and thoroughly dried, the tar is burned out (either by heating a cast steel ring placed in the furnace, or pouring some molten pig iron into the hearth), leaving behind a

sintered mass forming a solid basic lining. The furnace is then brought up to a high temperature by passing current through the ring of metal or the molten metal, until the furnace is ready to receive a charge.

Two methods of working are possible :—(1) cold charging and (2) hot charging. The former is usually adopted for the production of steel castings, and the latter for large quantities of better quality steel than can be conveniently obtained from the open-hearth or Bessemer plant. If cold charging is employed, the material is charged with the furnace and melted by the action of the induced currents and the heat generated by the side plates. When the bath is molten, the succeeding operation is similar to that of refining a molten charge. The addition of fluxes necessary and the chemical reactions involved, are considered in Chapter XLIV on "The Chemical Reactions in the Electric Furnace."

Cold Charging: Production of Steel Castings

Output and Cost of Furnace.—A 2-ton furnace (280–300 k.w.) working with common steel scrap, melting and refining, will produce about 8 tons per day of 24 hours. Assuming 250 working days per year, the annual output = 2000 tons. The cost of plant[1] is approximately £2350. Allowing 10 per cent. for depreciation and 5 per cent. for interest on capital outlay, the annual charge for the above = 15 per cent. of £2350 = £352 10*s.* 0*d.*

∴ Charge for depreciation and interest per ton of steel

$$= \frac{£352\ 10s.\ 0d.}{2000} = 3s.\ 6d.$$

Working Costs (per ton of Liquid Steel for Carbon Steel Castings)

Cost of Repairs: The cost of repairs to lining, plant, tools, etc., is given as 2*s.* 9½*d.* per ton of steel.

Cost of Power: About 700 k.w. hours are required for melting the charge, and an additional 200 k.w. hours for refining. (This latter figure depends of course upon the degree of refining desired.) At 0·3*d.* per k.w. hour, the cost of power = 900 × 0·3*d.* = 22*s.* 6*d.* per ton of steel produced. In addition to the above, power is required for tipping the furnace and for the fan used in cooling the transformer, costing approximately 2*d.* per ton.

Cost of Labour: 2 to 3 men are required to work the furnace, their total wages (at American rates) being equal to about 6*s.* 3*d.* per ton of steel.

Cost of Raw Materials: The following is given as typical of the proportions of materials used :—

	s.	*d.*
560 lbs. bundled scrap @ 46*s.* 10*d.* per ton	11	8½
560 lbs. machine shop and heavy turnings @ 38*s.* 6*d.* per ton	9	7½
1120 lbs. old steel rails @ 57*s.* 3*d.* per ton	28	8
Total	50	0
Add loss @ 5 %	2	6
Total cost	52	6

[1] "Transactions American Foundrymen's Association," 1911, p. 243.

The fluxes used per ton of steel average :—

Roll scale	22 lbs.	Cost 1*s.* 10*d.*
Lime	77 lbs.	
Fluorspar	11 lbs.	
Sand	20 lbs.	
Ferro-manganese	8·8 lbs.	

Summary of Costs

Cost of plant, £2350.

	£	*s.*	*d.*
Depreciation and interest	0	3	6
Repairs and tools	0	2	9½
Power for melting and refining	1	2	6
,, air cooling, and tipping furnace	0	0	2
Labour	0	6	3
Raw materials (steel scrap)	2	12	6
,, ,, (fluxes, etc.)	0	1	10
,, ,, (loss of fluxes due to ¼ of the metal remaining in the hearth)	0	0	8
Management expenses (50 % of labour)	0	3	1½
Royalty. Not included		—	
Cost per ton of liquid steel	£4	13	4

Hot Charging: Refining Molten Metal

The following summary of costs is for a 5-ton furnace refining hot metal from a mixer. The time required for each heat is about 2½ hours, and assuming an output of 40 tons per day of 24 hours, and 250 working days per year, the annual output = 10,000 tons.

The cost of plant[1] is approx. £3540, ∴ allowing 10 per cent. for depreciation and 5 per cent. for interest on capital outlay, the annual charge for above = 15 per cent. of £3540 = £531.

Charge for depreciation and interest per ton of refined steel

$$= \frac{531 \times 20}{10{,}000} = 1s.\ 1d. \text{ approx.}$$

Summary of Costs

Cost of plant, £3540.

	£	*s.*	*d.*
Depreciation and interest	0	1	1
Repairs and tools	0	2	8
Power for refining (280 k.w. hours @ 0·3*d.* per k.w. hour)	0	7	0
,, auxiliary apparatus	0	0	3
Labour	0	2	1
Raw materials (molten metal from mixer taken at 50*s.* ton)	2	10	0
,, ,, (fluxes, etc.)	0	2	6
,, ,, (oxidation loss @ 3 %)	0	1	6
Cost of refining in mixer	0	12	6
Management expenses (50 % of labour)	0	1	0½
Royalty. Not included		—	
Cost per ton of liquid steel	£4	0	7½

[1] "Transactions American Foundrymen's Association," 1911, p. 245.

THE FRICK ELECTRIC FURNACE

Description of the Furnace.—This furnace differs from the Kjellin in the arrangement of the primary windings. Fig. 227 is a sectional elevation. The primary windings are flat, and disposed both above and below the annular melting trough. The principle of working is similar to that of the Kjellin furnace.

The following particulars are given[1] of a 10-ton Frick furnace installed at the works of Messrs. Fried Krupp. The furnace is used for melting down good quality materials for the manufacture of high class steel, and is usually run with an 8½ ton charge, of which 6½ tons are tapped and the remaining 2 tons left in the furnace for the maintenance of the circuit for the next heat. The outside diameter of the furnace is 14 feet, and the annular bath is 9 feet outer diam. and

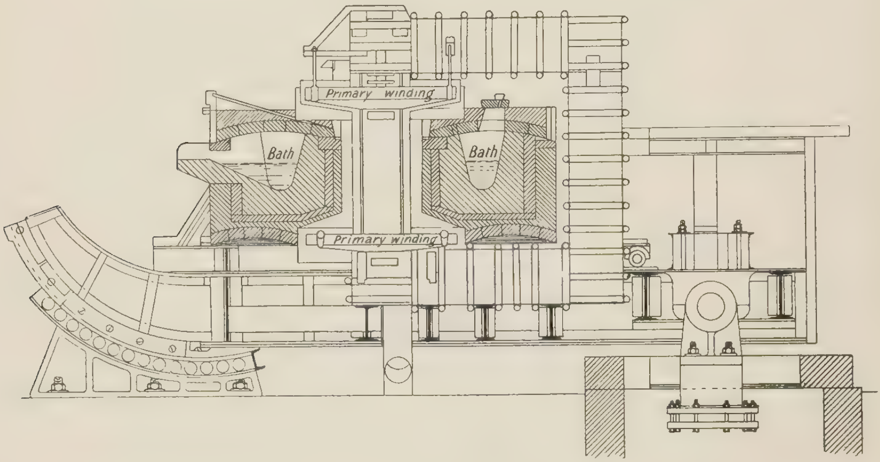


FIG. 227.—The Frick Furnace.

6 feet 4 inches inside diam. The primary current used is 5000 volts, at a frequency of 5 cycles per second, the current being 265 amperes. The power factor of the circuit is 0·528. The calculated current passing through the bath is 52,000 amperes, and the resistance of the bath 0·0002 ohm.

Operation of the Furnace.—The time taken per heat is 6½ hours; during the first 4½ hours the materials are charged into the furnace at the rate of ¼ ton at a time, whilst the remaining 2 hours are occupied in heating up the bath and refining the steel.

The power consumption per ton of steel produced averages 617 k.w. hours. The power supply of 590 kilowatts is absorbed as follows:—187 kilowatts to maintain temperature of furnace (*i.e.* in counteracting radiation and conduction losses), and the remaining 403 kilowatts are employed usefully in melting and refining the materials in the bath.

During an 8 weeks' run, this furnace made 180 charges, giving an output of 1150 tons.

The following are two analyses of steel made and the results of tests obtained. No data is given of the composition of the materials charged, but since the

[1] "Iron and Coal Trades Review," Aug. 26th, 1910, p. 320.

furnace is used for the production of high grade steel from good quality materials, very little refining is apparently carried out.

No.	Analysis of steel produced.					Mechanical tests.		
	C %	Si %	Mn %	P %	S %	Tensile strength. Tons per sq. inch.	Elong. %	Contraction of area %.
1	0·38	0·23	0·30	0·02	0·024	32·15	27·5	65
2	0·77	0·15	0·40	0·013	0·015	53·1	16·6	46

The Hiorth Electric Furnace

Mr. Hiorth constructed and patented a special type of electric furnace of 5 tons capacity and put it into operation early in 1910. In many places on the west coast of Norway, electric current can be developed from water power at a total installation cost of £5 to £6 per horse-power, and at a total working cost of 17*s.* per h.p. year. The plant at Jossingfjord, where the furnace is installed, comes within these conditions. Single-phase current at 250 volts, 12·5 cycles, is generated.

Description of the Furnace.—The 5-ton furnace at present in operation, is a double-channel induction furnace with the primary consisting of four coils connected in series. The upper coils are concentric with the heating channels, and are suspended from pulleys with flexible connections. When the furnace is in operation, the coils are close against the covers of the channels, but can be raised about 24 inches when the covers are to be removed. The upper coils are un-insulated bare copper bars, coiled spirally. The lower coils are hollow water-cooled copper conductors, and are embedded in the magnesite lining of the furnace, about 16 inches beneath the bottom of the channels. The space between the magnet and the furnace wall is about 12 inches, which allows the magnets to be bolted firmly to the floor, while at the same time the furnace can be tipped for pouring.

The junction of the two channels is 12 inches wide in the middle and 76 inches long from back to front, furnishing sufficient space for remelting ingots or other scrap. Four views of the arrangement are given in Fig. 228. The furnace is lined with burnt magnesite, and the covers consist of silica slabs.

The furnace is used chiefly for the production of steel of high grade crucible quality, the purest Swedish Dannemora pig-iron and Walloon iron being used. Blast furnace slag from the Dannemora furnaces is used as a flux, mixed with fluorspar if greater fluidity is required.

Operation of the Furnace.—When working the furnace up to its full capacity, 3 tons are poured at the end of the heat, and 2 tons are left to start the next charge. The Dannemora pig-iron used has an analysis of:—

C	Si	Mn	S	P
3·8	0·31	1·727	0·025	0·02 per cent.

and the Walloon iron an analysis of:—

C	Si	Mn	S	P
0·107	0·013	0·068	0·010	0·009 per cent.

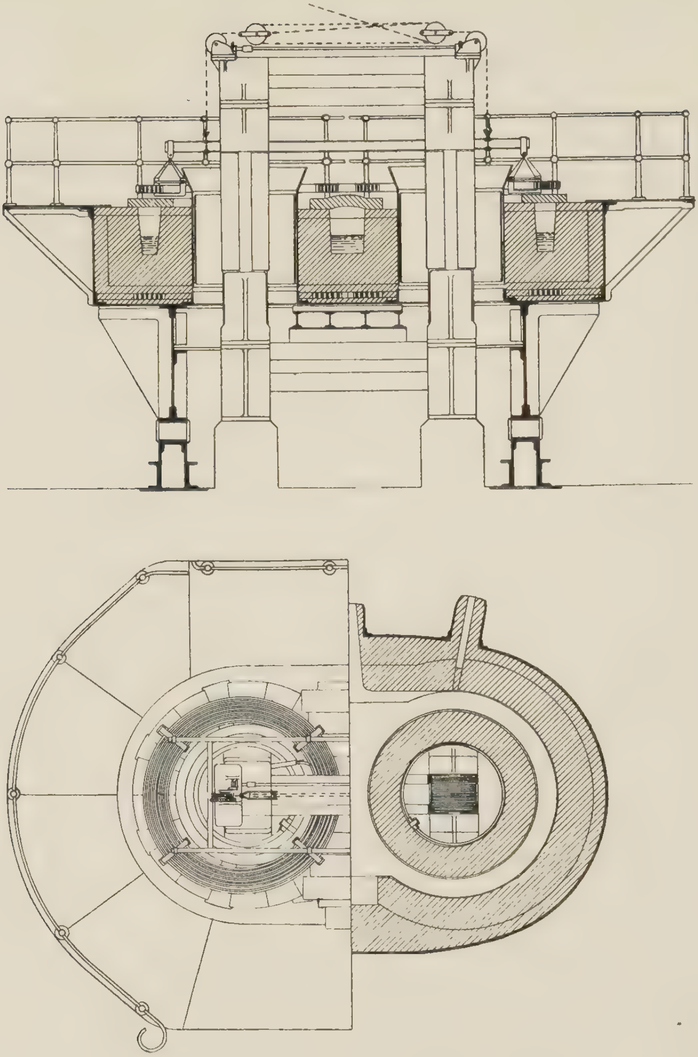


FIG. 228.—The Hiorth Furnace.

The following particulars illustrate the working of a charge in the furnace.

12.20 p.m. In furnace, 6100 lbs. of previous steel (1·0 per cent. carbon). Charged 2200 lbs. pig-iron and 1100 lbs. Walloon iron. Current switched on.
12·30 p.m. Current 1800 amps, 273 volts, 380 k.w.; power factor = 0·77.
1·30 p.m. ,, 1840 ,, 273 ,, 395 ,, ,, = 0·80.
2·0 p.m. ,, 2050 ,, 265 ,, 380 ,, ,, = 0·70.
2·30 p.m. Charge melted. Average power 380 k.w. for 2 hrs. 10 mins. = 560 k.w. hours per ton of metal melted.
2.30 p.m. Charged 770 lbs. pig-iron and 2530 lbs. Walloon iron.
3.30 p.m. Current 2275 amps, 270 volts, 400 k.w.; power factor = 0·65.

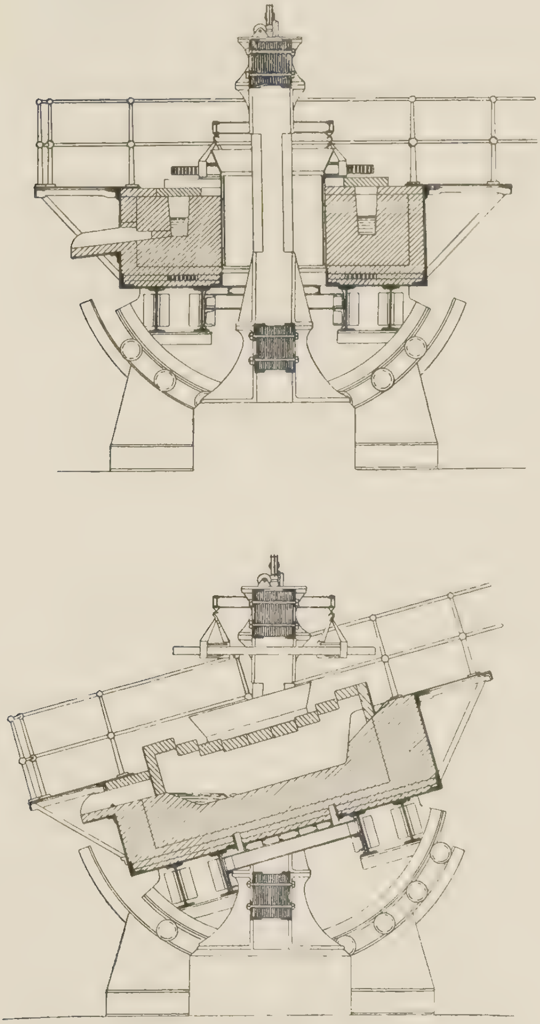


FIG. 228.

4.30 p.m. Charge melted. Average current 400 k.w. for 2 hours = 540 k.w. hours per ton of metal melted.

5.30 p.m.	Current 2370 amps,	265 volts,	395 k.w.;	power factor	= 0·63.
6·0 p.m.	,, 2425 ,,	278 ,,	400 ,,	,,	= 0·59.
6·15 p.m.	,, 2300 ,,	280 ,,	365 ,,	,,	= 0·57.

Metal now at casting temperature. Current used averaged 395 k.w. for 6 hours, or 805 k.w. hours per ton of steel.

During the heat there were added to the bath, 77 lbs. of 30 per cent. ferro-silicon, and 19 lbs. of 80 per cent. ferro-manganese. One-third of a pound of aluminium was added to the ladle.

The labour required on the furnace per 24 hours is: one head melter, one

helper, and one boy on each 12-hour shift, also one ladleman and one helper on every alternate 12-hour shift. The output of the furnace is 12 tons in 24 hours, tapping a 3-ton heat every 6 hours. When in regular operation 700 k.w. hours are used per ton of cold material melted.

The Paragon Electric Furnace

This furnace was introduced by the Grondäl Kjellin Co., with the object of combining the best features of the arc, induction, and resistance furnaces. By heating the bath of metal by carbon electrodes above the bath, and metal terminal plates built into the furnace lining below the bath, it is thought that the most advantageous conditions will be obtained. The furnace is still in the experimental stage, and no information as regards its commercial value can be given.

CHAPTER XLI

ARC RESISTANCE FURNACES

In this chapter are described the chief furnaces of the type where the heat is generated by means of arcs produced between the points of carbon electrodes situated just above the slag line, the current passing through the slag or surface of the metal and returning to the source of supply by means of one or more of the electrodes. The most important of the arc resistance furnaces is that introduced by Dr. Héroult in 1902. Fig. 229 shows the arrangement of a modern 5-ton three-phase furnace with equipment.

The Héroult Electric Furnace

Description of 15-ton Furnace.—The construction of the Héroult furnace will be more readily understood from the particulars, which follow, of a 15-ton furnace installed at the South Chicago Works of the Illinois Steel Co., U.S.A.

The furnace shell is of steel plates 1 inch thick, rivetted together, forming in plan a circle 13 feet 6 inches diameter, flattened at the front and back. To this shell is fastened a toothed segment which gears into a stationary rack fixed to a concrete bed, 5 feet above the ground-level. The segment has an arc of 10 feet radius, and gives a maximum tilting angle of 29 deg. to the furnace. To the back of the furnace is attached a hydraulic plunger 18 inches diameter by 4 feet stroke, which works at a pressure of 500 lbs. per square inch.

The furnace is lined with one $4\frac{1}{2}$ inch course of magnesite brick on the bottom, with vertical side walls of magnesite, 18 inches thick. The botttom is composed of dead burned Spaeter magnesite, 12 inches deep at the centre, sloping upward towards the edges to the form of the surface of a sphere, 7 feet 2 inches radius. The removable roof is composed of silica brick, 12 inches thick. There are 5 doors, 2 on each side and 1 in the front over the pouring spout. The side doors are of cast-iron lined with firebrick, and are operated by steam pressure.

The furnace works on 3-phase current, and the 3 electrodes form in plan the apexes of an equilateral triangle of 5 feet 2 inch side. The electrode holders, which are arranged to carry 24-inch electrodes (or the equivalent in electrodes built up of smaller sections), are constructed of copper castings, bolted to the busbars. They are regulated by an automatic device, by hand, or by controllers as desired.

For this particular furnace the power is generated at 2200 volts, 3 phase, 25 cycles, and stepped down at the furnace by means of three 750 k.w. transformers, which may be adjusted to give secondary voltages of 80, 90, 100, or 110 as desired. Ordinarily, 90 volts is used.

Fig. 230 is a photograph of the 15-ton furnace at the American Steel and Wire Co.'s Works, Worcester, U.S.A., which is similar to the furnace at South Chicago, described above.

Until recently, these furnaces were the largest in operation, but we under-

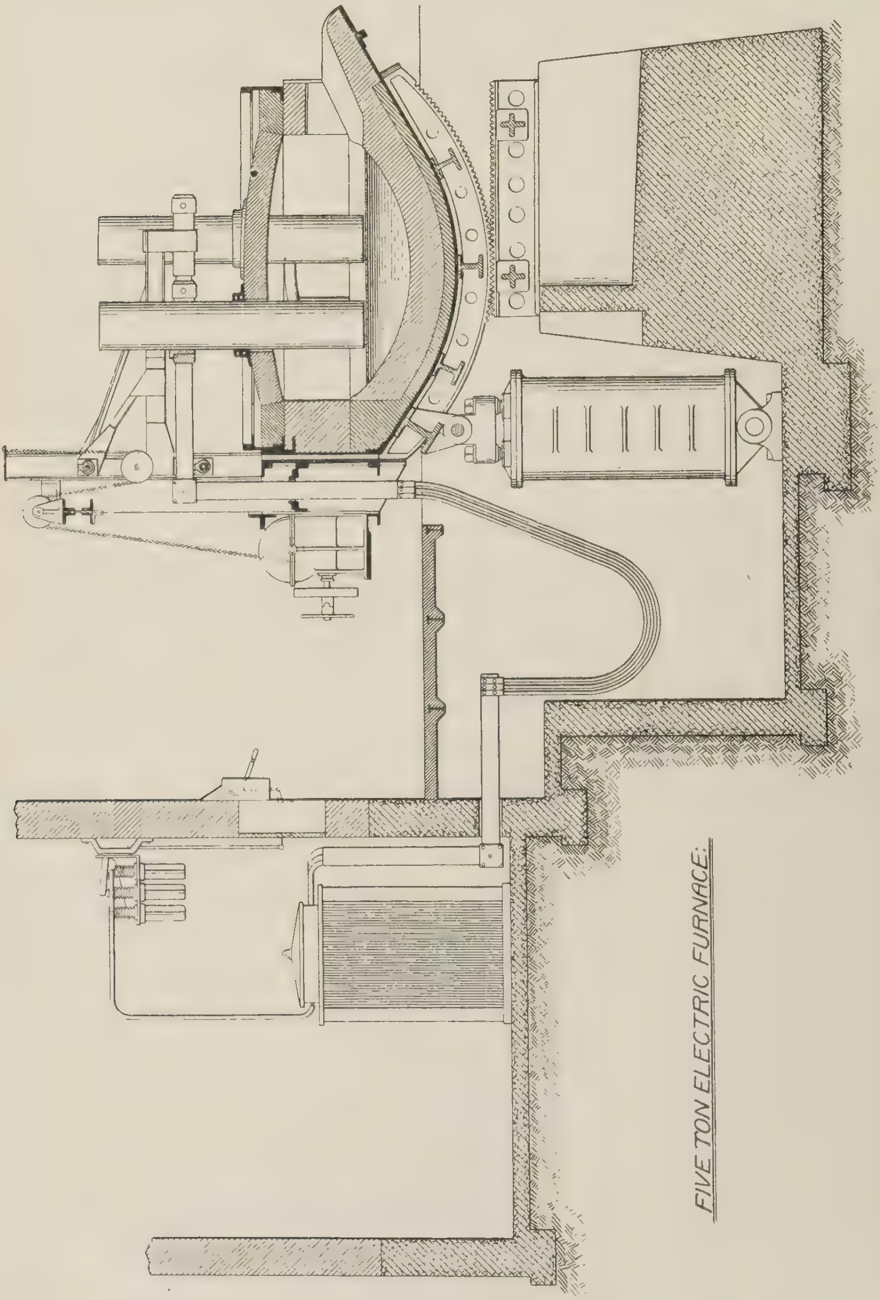


FIG. 229.—The Héroult Furnace.

stand that a 25-ton furnace has been installed at the Deutscher Kaiser

Co.'s Works in Germany, to work in conjunction with a 25-ton Bessemer converter.

The majority of the Héroult furnaces at work are of smaller capacity,

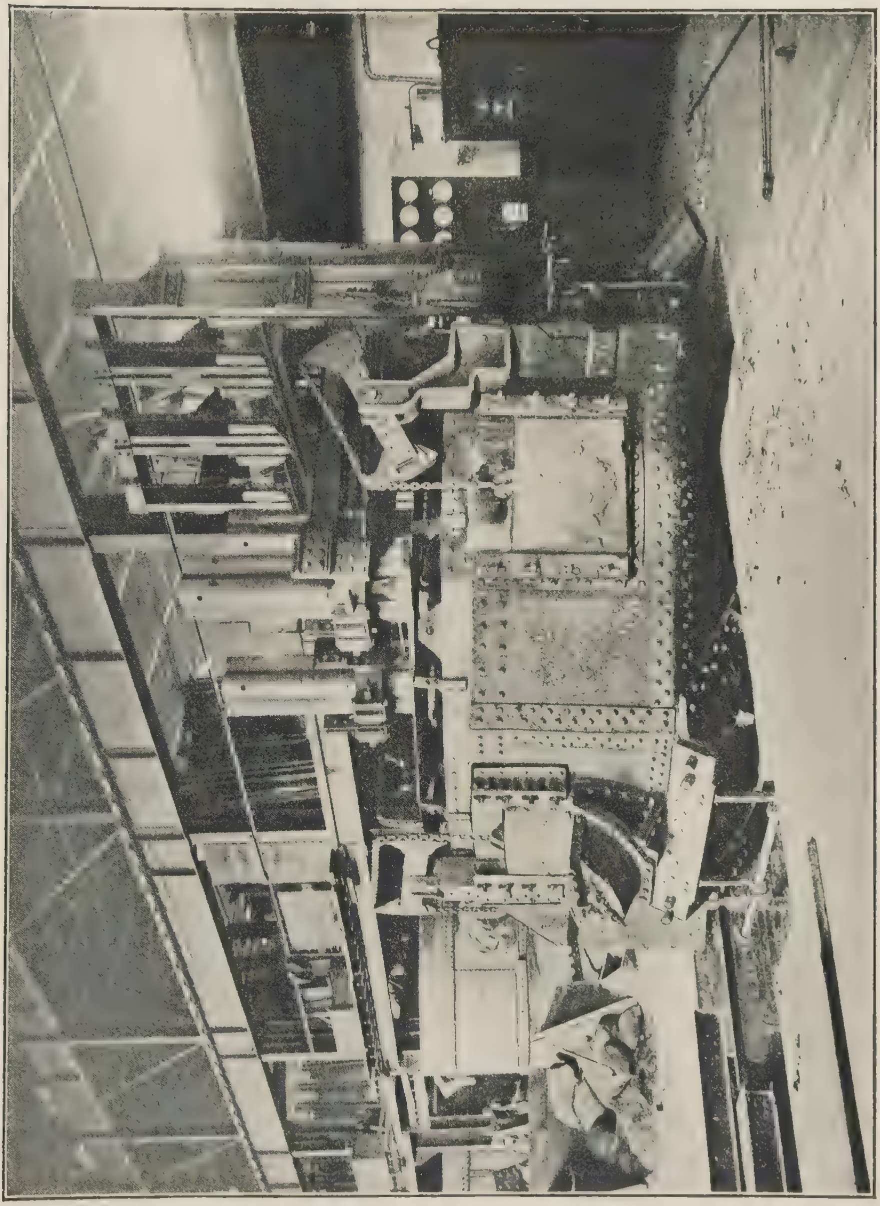


FIG. 230.—15-ton Héroult Furnace at Worcester Plant, American Steel and Wire Co., U.S.A.

i.e. from 1 to 7 tons, but the general principle and construction of each is the same.

Operation of the Furnace.—The larger sizes of furnaces are working on

molten metal charges, *i.e.* refining Bessemer or open-hearth metal for the production of better quality steel for rails, axles, wire, etc. Some of the smaller furnaces are used in this way, while others are melting scrap for the manufacture of steel for castings, tools, tubes, etc.

In starting the furnace, the lining is first thoroughly dried in the usual manner, and the lining gradually brought up to a high temperature by means of coal or coke fires, ready for the reception of the charge. If cold charges are being worked, iron ore, lime, and scrap are charged into the furnace, and the current switched on. When the scrap becomes molten, the refining is carried out in a similar manner to that adopted when working molten charges.

The following is a description of the operation of the 15-ton furnace at South Chicago : As the blown metal is being poured into the electric furnace, the workmen shovel in iron oxide and lime through the working doors. In this way a basic oxidising slag is produced, which serves to remove the phosphorus. After about 30 minutes, this slag is raked off and the recarburiser added. On to the bare surface of the oxidised metal, lime is then quickly added, with sufficient fluorspar to keep the mass fluid. At the end of about 15 minutes this lime is melted, and coke dust is thrown upon the slag. The atmosphere in the furnace becomes neutral, and when the slag reactions have been sufficiently carried out, tests are taken, and if these are satisfactory the electrodes are raised from the bath and the contents of the furnace poured.

The following particulars relate to a typical charge :—

	a.m.
Tapped previous heat from furnace	7.0
Metal ordered for and received	7.15
Began fettling	7.17
Current on	7.27
Slag off—began	8.0
,, ,, finished	8.11
Tapped	8.48

Materials used for typical charge :—

	lbs.
Blown Bessemer metal	30,000
Mill scale	700
Ferro-manganese (80%)	200
Ferro-silicon (10%)	60
,, ,, (50%)	80
Recarboniser	130
Fluorspar	400
Coke dust	200
Lime—first slag	600
,, second slag	600
Dolomite (for repairing)	400
Magnesite ,, ,,	25

The blown metal from the converter averages :—

C	Si	Mn	P	S
0·05 to 0·10%	0·005 to 0·015%	0·05 to 0·10%	0·095%	0·035 to 0·07%.

Twelve heats are usually made per 24-hour day. When both desulphurisation and dephosphorisation are necessary, the consumption of electrical energy is about 190 k.w. hours per ton ; where, however, the charge is low in phosphorus,

the consumption is 100 to 150 k.w. hours per ton. Fig. 231 shows chart of power consumption during the refining of a hot metal charge.

Working Costs. 15-Ton Furnace. Refining Molten Metal

The following costs of the working of furnaces of this capacity have been prepared from data in our possession.

Output and Cost of Plant.—The furnace makes an average of 12 heats per 24 hours, and assuming 280 working days per year, the annual output of refined metal = 12 × 15 × 280 = 50,400 tons.

An estimated cost of a 15-ton furnace (but excluding transformers or generating plant), is £3000. This does not include foundations, buildings, hydraulic supply, etc. Assuming that the cost of installation is £6000, and taking depreciation at 10 per cent., and interest at 5 per cent. on capital outlay, the annual charge = 15 per cent. of £6000 = £900.

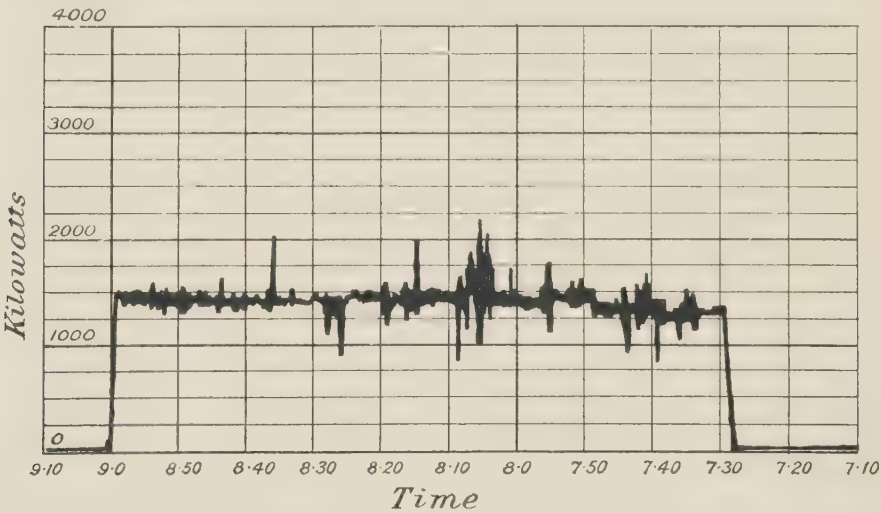


FIG. 231.—Power Chart, showing Consumption of Electric Current during Refining of Hot Metal Charge in Héroult Furnace.

∴ Charge for depreciation and interest per ton of steel refined

$$= \frac{900 \times 20}{50{,}400} = 4\tfrac{1}{2}d. \text{ approximately.}$$

Cost of Repairs.—A silica roof costs about £12 10*s.* 0*d.*, and lasts for 100–150 heats.

Taking an average of 125 heats, the cost of roof repairs per ton of steel

$$= \frac{£12\ 10s.\ 0d.}{125 \times 15} = \text{approx. } 2d.$$

The bottom of a 15-ton furnace lasts about 4000 to 5000 heats, with ordinary fettling between each heat. An estimate of general and ordinary repairs to lining, roof, and mechanical parts of plant is placed at 9*d.* per ton.

Cost of Power.—From 100–150 k.w. hours are required per ton of steel refined. Taking an average of 125 k.w. hours at 0·3*d.* per unit, the cost of

power per ton = 3*s.* 1½*d.* (The charge for electricity used by the 15-ton furnace at South Chicago is ¼*d.* per k.w. hour consumed.)

Cost of Electrodes.—From 10–14 lbs. of carbon electrodes are consumed per ton of steel. Taking the cost of electrodes at £14 per ton (1½*d.* per lb.), the average cost of electrodes = 1*s.* 6*d.* per ton of refined steel.

Cost of Labour.—One melter, one helper, and one labourer are required at the furnace, additional help being given when the furnace is being tapped and charged. No definite schedule of wages has yet been fixed for electric furnacemen, and each works settles the rates of pay to be adopted. An estimate of 9*d.* per ton for labour is therefore made.

Raw Materials.—Allowing 50*s.* per ton for the cost of the molten pig iron, and 12*s.* 6*d.* per ton for the partial refining in the Bessemer converter or open-hearth furnace, the cost of the partially refined metal delivered at the electric furnace is taken at 62*s.* 6*d.* per ton.

Fluxes and ferro-additions: at the proportions given in the typical charge set out on page 440, the cost of these materials per ton is taken at 3*s.* 9*d.*

Summary of Costs

Cost of plant, £6000 approx.

	£	s.	d.
Depreciation and interest	0	0	4½
Repairs	0	0	9
Power	0	3	1½
Electrodes	0	1	6
Labour	0	0	9
Raw materials (pig iron)	2	10	0
,, ,, (cost of partial refining)	0	12	6
,, ,, (fluxes and ferro-additions)	0	3	9
Loss of metal	0	2	0
Management expenses (50 per cent. of labour)	0	0	4½
Royalty—not included		—	
Cost per ton of liquid steel	£3	15	1½

Working Costs. 2½-ton Furnace producing Steel from Scrap for Steel Castings

Assuming a 2½-ton furnace to be installed (which is a fairly common size for use in small foundries), and working night and day shifts, 4 heats can be obtained per 24 hours. The average time per heat for melting and refining is 5 hours, although much depends upon the quality of the scrap used and the finished product required.

Output and Cost of Furnace.—A 2½-ton furnace (excluding transformer or generating plant) costs about £800. Taking the cost of the installation at £2000—assuming that power is supplied to the furnace from an outside source—and allowing 10 per cent. for depreciation and 5 per cent. for interest on capital outlay, the annual charge on this account = 15 per cent. of £2000 = £300. Working 260 days per year at 4 heats per day (24 hours), the annual output = 260 × 4 × 2½ = 2600 tons.

∴ Charge for depreciation and interest per ton of steel

$$= \frac{300 \times 20}{2600} = 2s.\ 4d.$$

Summary of Costs

Per ton of liquid steel for carbon steel castings. The following costs have been compiled from data in our possession :—

Cost of plant, £2000 approx.

	£	s.	d.
Depreciation and interest	0	2	4
Repairs to walls, roof, and mechanical plant (roof lasts about 80 heats)	0	2	6
Power, 750 k.w. hours at 0·3*d.* per unit	0	18	9
„ heating up at week-ends	0	1	0
Electrodes, 30–40 lbs. (average 35 lbs.) at 2*d.* per lb.	0	5	10
Labour—1 melter, 1 helper, and 4 labourers	0	6	0
Raw materials, 19 cwt. scrap at 55*s.* ton; „ „ 2 cwt. pig-iron at 65*s.* ton	2	18	9
„ „ fluxes and ferro-alloys	0	4	6
Management expenses (50 per cent. of labour)	0	3	0
Royalty—not included		—	
Cost per ton of liquid steel	£5	2	8

The Cutts Electro-Bessemer Furnace

This furnace has been designed with the object of combining the Bessemer and electric processes, by refining Bessemer steel in the same furnace with the aid of electric arcs, thus avoiding the necessity of transferring the blown metal from the converter to an electric furnace, as is done in the ordinary duplex process.

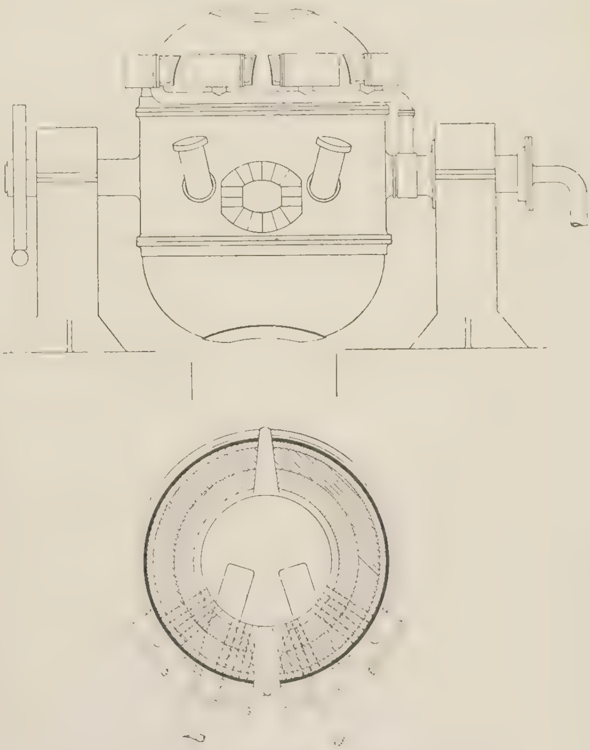


Fig. 232.—Cutts Electro-Bessemer Furnace.

Description of the Furnace.—The furnace shown in Fig. 232, is a closed vessel mounted on trunnions, having an opening on one side through which the charge is introduced and the slag withdrawn. One end of the furnace is fitted with blast tuyeres for "blowing"; at the other end electrodes are arranged, which pass through the furnace lining, and are adjusted by the ordinary independent methods, either

electrical or mechanical. The electrodes are fitted with cooling jackets of cold air or water. A tapping hole is provided at the electrode end of the furnace, which may be used for the removal of the finished product if desired.

Operation of the Furnace.—The furnace is pre-heated in the ordinary way, and is then charged with the molten metal direct from the cupola or blast furnace mixer, the furnace being previously tilted into the horizontal position. It is then brought to a vertical position with the Bessemer portion containing the charge. The blast comes into action as this position is reached, and the process of conversion proceeds as in the ordinary Bessemer converter. Meantime, the electric portion of the furnace is heated by the hot gases, etc., evolved from the blow. On the completion of the blow, the furnace is rotated through 180 degs., and the metal transferred to the other end. The current is switched on, and the refining operation carried out.

It is claimed that the utilisation of the flame from the Bessemer operation heats the hearth to such an extent where the electrical refining is carried out, that a considerable saving of electrical energy occurs during the second stage of the process. If the phosphorus content is low when the electrical operation commences, the energy consumption is said to be less than 100 k.w. hours per ton of steel produced. If, however, both desulphurisation and dephosphorisation are to be carried out, about 190 k.w. hours per ton of steel are consumed.

The Ruthenburg Electric Furnace

Description of the Furnace.—This furnace is designed for three-phase alternating current, and the ends of the electrodes are immersed in the slag, the voltage being below that necessary to produce arcs. The general arrangement of a 12-inch electrode furnace is shown in Fig. 233. The furnace is cylindrical, and is built up of mild steel plates, lined with an acid or basic lining as desired.

The hearth is removable, and when the melt is completed, a hydraulic ram is brought into contact with the underside of a truck fixed to the hearth, the hinged bolts are released, and the hearth is lowered and carried away on the truck, the steel being poured over the lip at one side by the aid of a crane, see Fig. 234. The repairing of the hearth is easily carried out, and if a new lining or extensive repairs are required, a spare hearth, kept in readiness, can be quickly substituted. The time required for lowering the hearth, pouring, and replacing is about 12 minutes.

The electrodes are protected by water-jackets, which extend to within a few inches of the bath. By this means it is claimed that the fritting experienced with unprotected electrodes is avoided. The electrode holders are made the same size as the electrodes, so that the whole of the electrode may be fed through the jacket, resulting in 90 per cent. being available for use. By the foregoing means for utilising the electrodes, the original necessity for bringing the furnace cover near to the heat zone is avoided, and consequently the furnace is constructed with the crown at a considerable height above the level of the bath. One furnace, which has been at work for three years, has not yet had the crown renewed.

Operation of the Furnace.—Before the charge of metal is introduced, a bath of slag is first melted in the hearth. Low carbon scrap in compressed bundles is then charged at the side door above the bath, whilst light scrap is fed in through the hopper at the top. Pig iron with scrap, or ore, can be melted and refined in the furnace if desired. The slag can be tapped off if necessary through the pouring lip of the hearth, the hole being opened with a bar in the usual way.

The process, worked usually with cold scrap, is almost entirely a melting one, pure materials being charged in such proportions to give approximately the desired final analysis. The furnace is operated by current of constant amperage, as opposed to the ordinary supply of constant voltage. This enables the voltage to vary with the resistance of the bath, and once a bath is established, the power demand remains practically constant. It is stated that the power factor of this furnace is about 90 per cent.

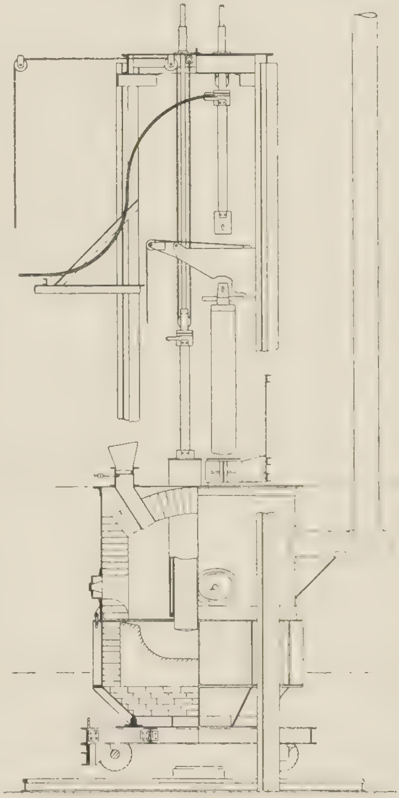


FIG. 233.—The Ruthenburg Furnace.

Working Data and Costs.—A 1-ton furnace has 10-inch electrodes, with hearth 48 inches diam., and bath of metal about 6 inches deep. A charge of mild steel scrap takes 4 hours to melt, which at 250 kilowatts = a consumption of 1000 k.w. hours. Working with pig and scrap or pig and ore, this figure would be somewhat lower.

The cost of maintenance of the furnace amounts to about 2*s.* per ton. The consumption of electrodes amounts to 25 lbs. per ton of steel produced, which at 2*d.* per lb. = 4*s.* 2*d.* The labour is confined to the head melter and the common labour required to charge the scrap and pour the steel.

The cost of the furnace is approximately £100 per 1 inch diam. of electrodes, *i.e.* a 1-ton furnace having 10-inch electrodes would cost, approximately, £1000.

THE GIN ELECTRIC FURNACE

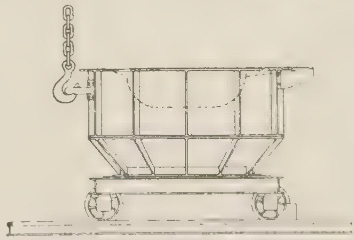


FIG. 234.—Removable Hearth of Ruthenburg Furnace, showing Method of Tipping Charge.

The Gin furnace is not so much a new type of furnace as the application to existing types of an arrangement which has been designed with the object of circulating the metal in the bath.

Various methods have been adopted by inventors of electric furnaces for circulating the molten metal so that it may all in its turn come into contact with the refining slags. With a view to solving this difficulty, the Gin furnace has been introduced, the arrangement of which can, it is claimed, be applied to both induction and electrode furnaces.

Fig. 235 shows its application to an electrode furnace. Dependant upon whether single phase or three phase current is employed, the furnace is arranged with two or three hearths, one beneath each carbon electrode, and these are connected together below the level of the molten metal in them by inclined

channels. The current passing down one electrode, traverses the bath, passes through the connecting channels, and out through the other bath and electrode. It is stated, that by reason of the heat induced in the connecting channels, and

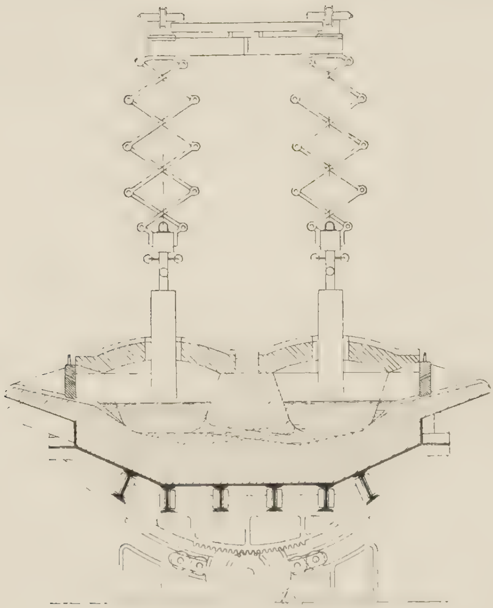


FIG. 235.—The Gin Furnace.

the difference in level between their ends, the molten metal rises in them and passes from one hearth to the other, with the result that a continuous circulation is set up, which tends to maintain the metal at an even temperature.

CHAPTER XLII

COMBINED ARC AND RESISTANCE FURNACES

The type of furnaces described in this chapter embodies the combined features of arc and resistance furnaces. In such furnaces, current is carried through electrodes suspended over the metal, through which it passes to pole pieces, or electrodes built into the sides or bottom of the furnace. It is claimed by makers of these furnaces that the metal is heated more uniformly than with arc resistance furnaces. Owing to the very small resistance, however, which a bath of metal sets up, the heat produced by the passage of current through the bath is very small compared with the heat of the arc, and consequently but little advantage can be obtained by this means. A difference of opinion exists as to the advantage or otherwise of pole pieces built into the lining of a furnace. Simplicity of design is, however, of great importance, if these furnaces are to be of real practical and commercial value.

All furnaces described in this chapter are more or less modifications of Sir Wm. Siemens' original furnace, illustrated in Fig. 220 *b*, p. 418, and many of the designs are practically the same, but for small details introduced with the object of promoting more efficient working.

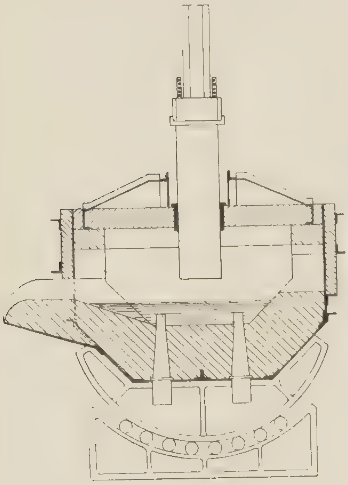
The Girod Electric Furnace

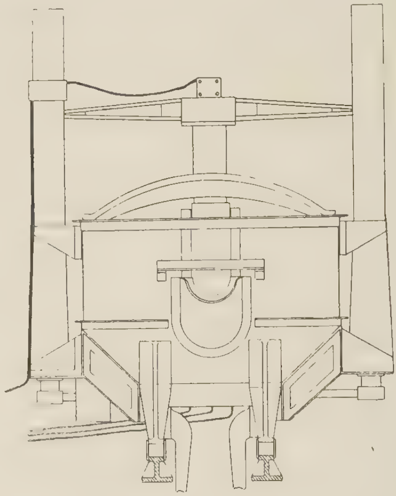
Description of the Furnace.—The arrangement of the Girod furnace will be seen from Fig. 236, which illustrates a furnace of $2\frac{1}{2}$ tons capacity. The furnace consists of a shell, built up of steel plates (circular or rectangular in plan), lined with basic material, and provided with doors in the walls for charging, teeming, and slagging. The whole is mounted upon a cradle and tipped electrically or hydraulically. The roof is composed of silica bricks, with which cast-iron water-cooled blocks are built, and through which the electrode or electrodes pass. The number of electrodes is determined by the size of the furnace. The current, which may be either continuous or alternating, enters by the upper electrode (or electrodes), arcs across the gap between the end of the electrode and the slag, traverses the metal bath, and passes out through steel pole pieces built into the bottom of the furnace. These steel pole pieces are in direct contact with the bath, and become molten at their extreme ends when the furnace is working, while their outer ends are water-cooled as shown in Fig. 237. Since all the arcs are in parallel, the furnace works at a low voltage, *i.e.* about 50 volts. The carbon electrodes are fitted with hand and automatic regulators. The bath is heated both by the arcs and by the resistance set up by the slag and metal to the current passing through them, but by far the greatest amount of heat is obtained from the arcs, which presumably set up the circulation of the bath necessary for the refining reactions. This furnace is used for the production of steel from the cold charge, or for the refining of molten metal.

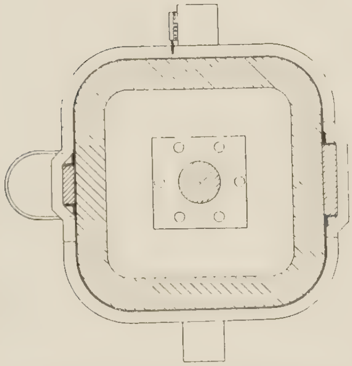
In early designs, the electrical connections were arranged as shown[1] in

[1] "Stahl und Eisen," 1911, July 20th.

Fig. 238 (*a*), with the object of connecting up the furnace to the supply with as







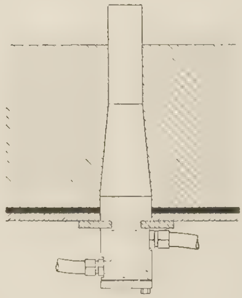
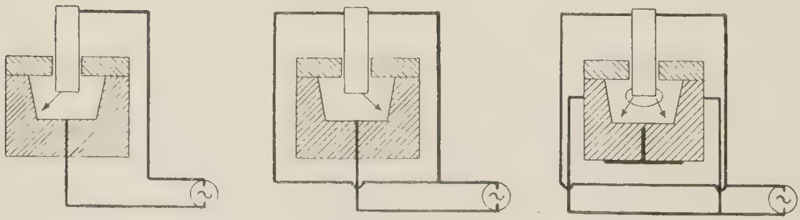


FIG. 236.—The Girod Furnace.

FIG. 237.—Water-cooled Electrode : Girod Furnace.



(*a*). (*b*). (*c*).

FIG. 238.—Electrical Connections for Girod Furnace.

little expenditure on cable as possible. This resulted, however, in the arc being deflected towards the side indicated by the arrow, and consequently the bath

was not heated uniformly, and also, the lining on the side of the furnace most exposed to the arc was rapidly destroyed. With a view to remedying this, the arrangement of cables shown in Fig. 238 (*b*) was adopted, but here again the arc was deflected to one side with the same results as before. In each of these cases the steel pole pieces were insulated from the furnace shell. In the latest design, the connections are arranged as in Fig. 238 (*c*), the return current from the bottom electrodes being tapped from the furnace shell (which is in contact with the pole pieces) above the metal bath. This has resulted in a more uniform heating of the bath, and a longer life of the walls and roof. In addition, it is stated by the inventors that a swirling arc is formed which stirs up the bath, the consumption of electrodes is more uniform, and a saving of energy of about 10 per cent. over the original method is effected. Fig. 239 shows a diagram of the electric circuit of the furnace.

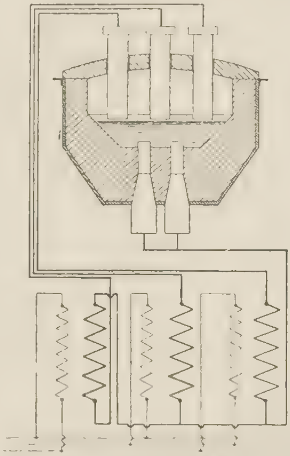


FIG. 239.—Diagram of Electric Circuit: Girod Furnace.

The size of the furnace and the time between successive heats, the condition of the charge and the quality of the final product, have a considerable bearing upon the consumption of energy. With a furnace of 3 tons nominal capacity, working with charges of varying weight

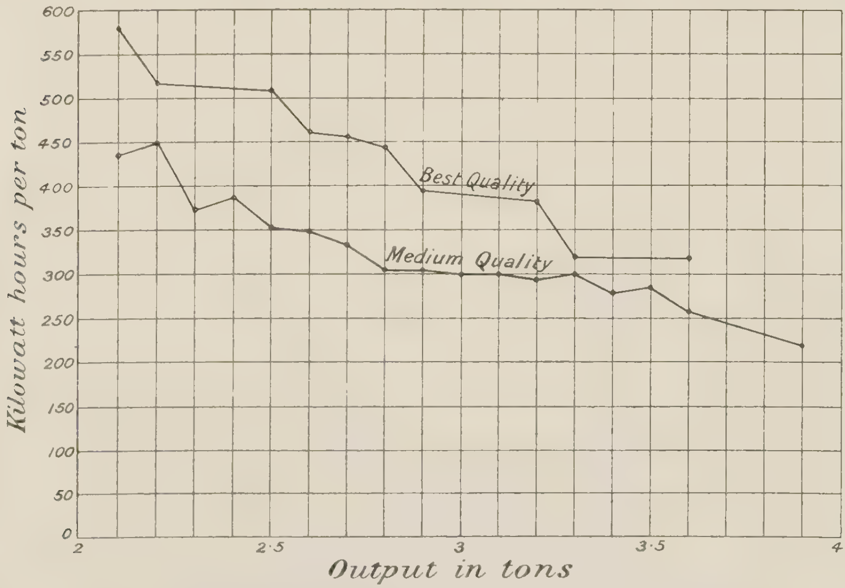


FIG. 240.—Energy consumed per ton of Steel Refined: Girod Furnace.

refining molten open-hearth steel, the energy consumption for best quality and medium quality steels is given in Fig. 240. The values plotted are the results of actual working.

Either magnesite or dolomite is used for the lining of the hearth and walls, the roof being of silica bricks.

Operation of the Furnace.—The refining of a charge in the furnace is divided into two periods :—

(1) The oxidation period.

(2) The deoxidation period.

If a cold charge is being worked, the scrap is melted down until it becomes liquid, and the temperature attains that of a charge put into the furnace hot. Ore is then added gradually to the bath, and the carbon, manganese, phosphorus, and part of the sulphur are oxidised. The oxidising slag is withdrawn at the end of this period, and the last removable traces of phosphorus are removed by means of lime. The deoxidation and desulphurisation are carried out by the addition of lime, sand and fluorspar, ferro-silicon, and petroleum coke or waste pieces of carbon electrodes. As soon as the slag is fluid and free from oxide, the additions of ferro-silicon and ferro-manganese are made, and the charge is poured.

Output and Cost of Furnace.—The cost[1] of a $2\frac{1}{2}$-ton furnace, including regulators for the electrodes, measuring instruments, tilting mechanism, and conductors from the furnace to dynamo or transformer if placed near the furnace, = £600 approximately. A $12\frac{1}{2}$-ton furnace with similar outfit costs approximately £1200. The output of either size of furnace depends of course upon whether it is being used for melting and refining, or refining only, and also upon the degree of refining required. A $2\frac{1}{2}$-ton furnace melting cold pig iron and steel scrap, producing good quality steel castings, will produce a heat in about 6 hours, or 4 heats per 24-hour day. A furnace of this size would therefore give an output of about 50 tons of liquid steel per week, or 2500 tons per year of 250 working days.

Assuming the furnace to be supplied with current from an outside source, the cost of installation of a $2\frac{1}{2}$-ton furnace would be about £2000. Allowing 10 per cent. depreciation and 5 per cent. interest on the outlay, the annual charge for depreciation and interest = 15 per cent. of £2000 = £300.

∴ Charge for depreciation and interest per ton of liquid steel

$$= \frac{300 \times 20}{2500} = 2s.\ 5d.$$

Working Costs (per Ton of Liquid Steel for Carbon Steel Castings)

Cost of Repairs.—The figure of 12*s.* per ton is given[2] for the cost of upkeep of furnace and wear and tear of plant. The intense heat of the arcs necessitates frequent repairs to the lining, and renewal of the brickwork of the walls and roof. When used for refining only, a $2\frac{1}{2}$-ton furnace roof will only stand from 60 to 70 heats, while the walls must be rebuilt after 120 heats, at the end of which time the hearth must be thoroughly repaired. The cost of a dolomite lining for a $2\frac{1}{2}$-ton furnace is about £17 10*s.*, and a magnesite lining, £35. The cost of repairs and upkeep will be taken as 12*s.* per ton of liquid steel.

Cost of Power.—The consumption of power for a $2\frac{1}{2}$-ton furnace when producing good quality steel from common scrap is 800 to 900 k.w. hours per ton, and allowing 10 per cent. loss in the conductors, the figure of 1000 k.w. hours per ton is given. With selected scrap, which will give the required analysis of steel when melted, and thus reduce the refining operations, the power consumption varies from 650 to 750 k.w. hours per ton. This necessitates, of course, the use of

[1] "Journal Iron and Steel Institute," 1910, I, p. 151.
[2] "Foundry Trade Journal," 1909, p. 150.

purer materials, so that, although the cost for power is thereby reduced, an increased cost on materials is entailed. For refining fluid open-hearth or Bessemer metal, the power consumption is about 300 to 350 k.w. hours per ton. Fig. 241 shows the fluctuations in current during a heat.

It is interesting to note that a $2\frac{1}{2}$-ton furnace having one carbon electrode and 6 hearth poles, requires about $4\frac{1}{2}$ gallons of water per minute for cooling the carbon electrode in the roof, and $1\frac{1}{5}$ gallons per minute for cooling the poles in the hearth. This water abstracts an amount of heat from the furnace equal to 13·4 k.w. hours per ton of steel, when the furnace is used for refining molten metal.

Taking 1000 k.w. hours per ton as the consumption for melting and refining common scrap and producing good quality steel for castings, and with power taken at 0·3*d.* per unit, the cost of power per ton of liquid steel = 1000 × 0·3*d.* = £1 5*s.*

Cost of Electrodes.—The cost of electrodes per ton of steel produced is

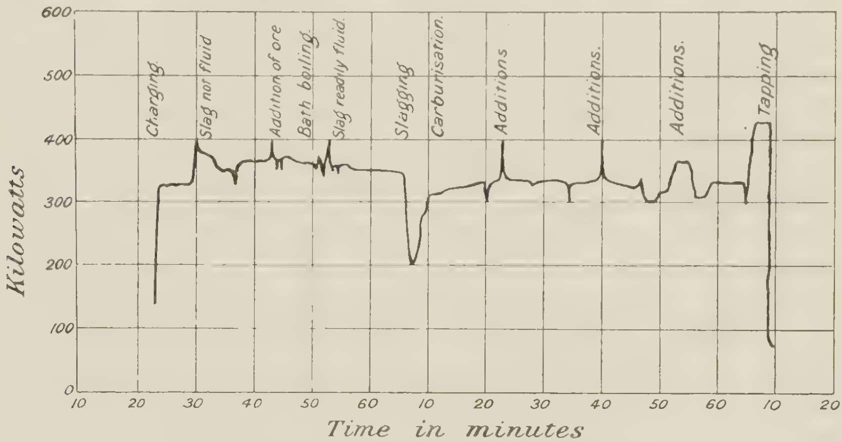


FIG. 241.—Power Fluctuations during Heat: Girod Furnace, Refining Charge.

given as 4*s.* if the furnace is used for melting and refining common scrap, 3*s.* 2*d.* if melting good quality scrap, and 1*s.* 7*d.* if refining molten metal.

Cost of Labour.—To work a $2\frac{1}{2}$-ton furnace, one melter, one melter's assistant, and one boy are required. The cost of labour paid per ton of liquid steel (according to Continental standards) is 4*s.* 9*d.* when the furnace is melting and refining common scrap, 3*s.* 2*d.* if melting good quality scrap, and 2*s.* 5*d.* if refining molten metal.

Cost of Raw Materials.—The raw materials used in the furnace include the scrap steel, together with the oxidising and refining materials such as iron ore, lime, etc., and the alloy additions. The loss in melting and refining steel scrap is 3 to 4 per cent., so that with common scrap at 55*s.* per ton, the cost of scrap material per ton of liquid steel produced = 57*s.* To refine and "physic" the molten metal, the quantity of lime, fluxes, and ferro-alloys will depend upon the kind of scrap available and the desired analysis of the finished steel. An average cost, which includes 2 cwts. of lime, 2 cwts. of iron ore, and alloy additions, is 2*s.* 5*d.* per ton of liquid steel.

The following summaries of costs, Nos. 1 and 2, are for the production of steel for castings of similar quality to that given in Table LXII, p. 245, and Table XCIII, p. 473. The terms "cheap" and "good" scrap refer to ordinary and selected scrap respectively.

Summary of Costs

1. Producing good quality carbon steel castings from cheap scrap.

Cost of plant, £2000.

	£	s.	d.
Depreciation and interest	0	2	5
Repairs	0	12	0
Power	1	5	0
Electrodes	0	4	0
Labour	0	4	9
Raw materials—Steel scrap (cheap quality)	2	17	0
Fluxes and ferro-additions	0	2	5
Management (50 per cent. of cost of labour)	0	2	4½
Royalty—not included		—	
Cost per ton of liquid steel	£5	9	11½

2. Producing good quality carbon steel castings from good scrap.

Cost of plant, £2000.

	£	s.	d.
Depreciation and interest	0	2	0
Repairs	0	9	6
Power	0	18	9
Electrodes	0	3	2
Labour	0	3	2
Raw materials—Steel scrap (good quality)	3	2	0
Fluxes and ferro-additions	0	0	5
Management (50 per cent. of cost of labour)	0	1	8
Royalty—not included		—	
Cost per ton of liquid steel	£5	0	8

3. Refining molten Bessemer or O.H. steel.

Cost of plant, £2000.

	£	s.	d.
Depreciation and interest	0	1	0
Repairs	0	4	0
Power	0	8	6
Electrodes	0	1	7
Labour	0	2	5
Raw materials—Pig iron	2	10	0
(cost of partial refining)	0	12	6
Fluxes and ferro-additions	0	1	7
Loss of metal	0	2	0
Management (50 per cent. of cost of labour)	0	1	2½
Royalty—not included		—	
Cost per ton of liquid steel	£4	4	9½

The Anderson Electric Furnace

Description of the Furnace.—The arrangement of the Anderson furnace will be seen from the accompanying Fig. 242. The furnace resembles a tilting open-hearth furnace, the roof of which is pierced for the electrodes connected to the

electrical supply either in series or in parallel, according to the work for which the furnace is designed. Immediately beneath the base of the furnace, and in line with each electrode, are fixed electro-magnets, the object of which is to control the arcs and to counteract any interference to their formation. It is also claimed that these electrodes concentrate the incandescent gases around the arcs, so that their heat may be imparted to the bath to the best advantage. For furnaces of small capacity one electro-magnet only, as shown in the illustration, is found to be sufficient. The furnace is provided with a pouring lip and with tapping holes, from which the metal and slag can be tapped as required. The electrodes, which are water-jacketed, are raised and lowered by any suitable means.

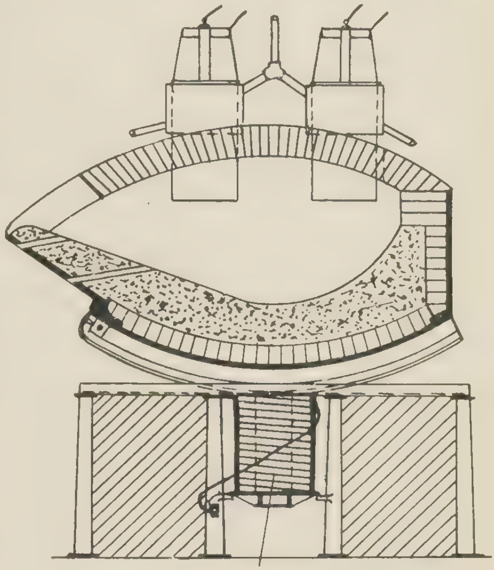


FIG. 242.—The Anderson Furnace.

Operation of the Furnace.—When used for refining molten metal, the charge is covered with an oxidising slag which is allowed to remain for about thirty minutes, and then skimmed off. A layer of carbon is then spread over the surface of the molten metal, and over this a slag free from oxygen. The neutral slag cools the mass and results in the reduction of the ferrous oxide by the carbon. Manganese ore is then added to the neutral slag and completes the elimination of any remaining ferrous oxide. When the slag is perfectly white a carbon test is made, and a mixture of iron and carbon, together with the necessary alloys, is added in such amounts determined by calculation as will give the analysis required. A molten charge can be refined in from 1 to $1\frac{3}{4}$ hours, with an average power consumption of 270 k.w. hours per ton.

When using the furnace for melting and refining, the scrap, together with a little ore and lime, is charged, the current switched on, and the material reduced to a molten condition by the combined arc and resistance heating. A slag, formed by the lime and silicates of the ore, floats on the surface of the bath, and into this the electrodes dip, but not into the metal itself. An air blast is then introduced, and the impurities of the charge become oxidised and enter the slag, which is withdrawn. If a very pure product is required, one or two additional slags may be formed. When the last slag is withdrawn, the necessary alloys are added and the charge tapped.

The following is a typical cold charge :—

Ordinary steel scrap	5800 lbs.
Iron ore	390 ,,
Lime	370 ,,
Ferro-silicon	18 ,,
Ferro-manganese	3 ,,

The charge takes about six hours to melt and refine, with an average power consumption of 975 k.w. hours per ton of steel produced.

Cost of Refining Molten Metal per ton.—The following figures are given by the inventor, and are the result of actual working costs:—

	£	s.	d.
Depreciation and interest	0	3	9
Repairs and renewals	0	4	0
Power, 210 k.w. hours @ 0·3*d*. per unit	0	5	3
Electrodes	0	1	6
Labour	0	5	0
Additions—ferro-alloys, lime, and slags	0	6	4
General management and sundries	0	2	6
Royalty—not included		—	
Cost of refining per ton of liquid steel	£1	8	4

Melting and Refining from Cold Scrap—

	£	s.	d.
Depreciation and interest	0	8	0
Repairs and renewals	0	4	0
Power, 750 k.w. hours @ 0·3*d*. per unit	0	18	9
Electrodes	0	3	6
Labour (4 men)	1	4	0
Raw materials—Good quality scrap @ 60*s*. ton	3	8	0
Lime, ore, etc.	0	5	0
Ferro-alloys	0	4	6
General management	0	3	0
Royalty—not included		—	
Cost per ton of liquid steel	£6	18	9

The Chaplet Electric Furnace

Description of the Furnace.—The Chaplet furnace is made in two types, fixed and tilting, and consists essentially of a casing lined with refractory material, leaving a circular hearth in the middle, which is covered with a removable refractory arched roof, held together in an iron frame. The arrangement of the tilting type of furnace is shown in Fig. 243. The furnace has only one arc, the roof being pierced in the centre for the entrance of one carbon electrode, whilst the return current is transmitted to the circuit through the bath to a fixed steel electrode sunk in the furnace lining away from the hearth, and connected to the metal bath by means of a solid bar in a horizontal channel, as shown in the illustration. When the furnace is first started, contact between the base of the steel electrode and the charge in the furnace is made by means of iron bars set at the bottom of the channel. As soon as the charge is molten, it flows along the channel, adheres to the steel electrode, and becomes solidified in this part, thus forming an uninterrupted passage for the current as long as the furnace is operated.

The tilting furnace may be mounted on rollers and cradle, or on a simple pivot as shown in the illustration, in which case the tilting is performed by a hydraulic ram. The electrode is raised or lowered by the gearing of the leg crane which supports the electrode.

The furnace may be used for melting only, or for melting and refining. The loss in the finished charge is estimated at from 3 to 5 per cent. The following

particulars of the working and cost of production in a 3-ton furnace have been supplied by the patentees :—

Cost of a 3-ton Furnace.—

Fixed type :—

	£
Groundwork and pit	40
Ironwork and crane	116
Interior lining	64
Various posts, electrode holder, etc.	60
Total (exclusive of copper conductors)	£280

A tilting furnace of the same capacity costs about £400.

Working Data and Costs.—The cost of maintenance of the whole of the furnace is about 5*s*. per ton of steel produced, if working with cold charges. For melting and refining, the consumption of electrodes is 24 to 27 lbs. per ton, whilst for melting and refining the consumption is 33 to 35 lbs. per ton. The time taken to melt 3 tons of steel is 7 to 8 hours, whilst to melt and refine the same quantity, 9 to 10 hours are required. The power consumption when the furnace is used for melting only is 715 to 740 kilowatt hours per ton. For melting and refining, the consumption is 915 to 970 k.w. hours per ton. (For furnaces of larger capacity, these figures would probably be decreased.) Assuming electrical power to be taken from supply mains at 0·3*d*. per unit, the average cost per ton for melting only is therefore 18*s*. 3*d*., and for melting and refining £1 3*s*. 8*d*.

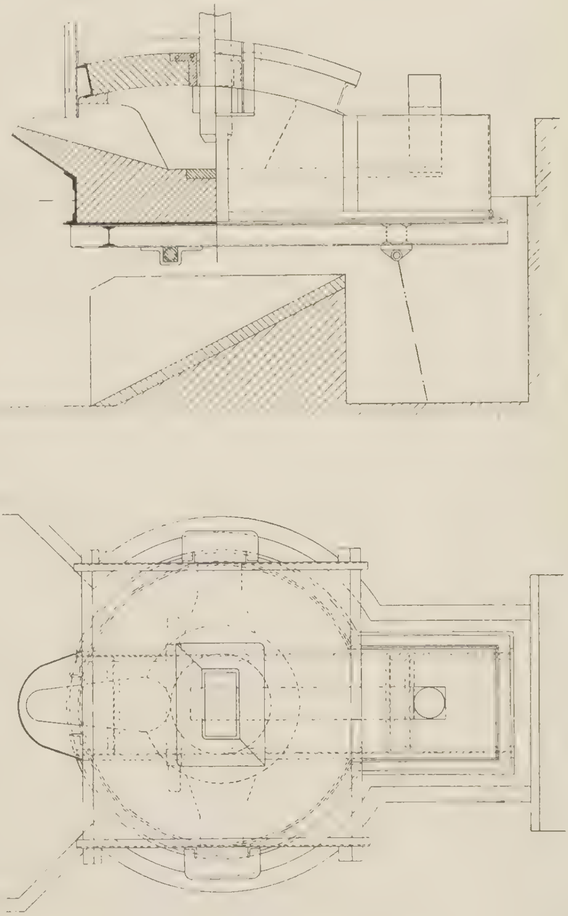


FIG. 243.—The Chaplet Furnace.

THE ELECTRO-METALS ELECTRIC FURNACE

Description of the Furnace.—The Electro-Metals furnace is constructed under the Grönwall, Lindblad, and Stahlane patents. Its outward appearance resembles a tilting open-hearth furnace, with two electrodes passing through the

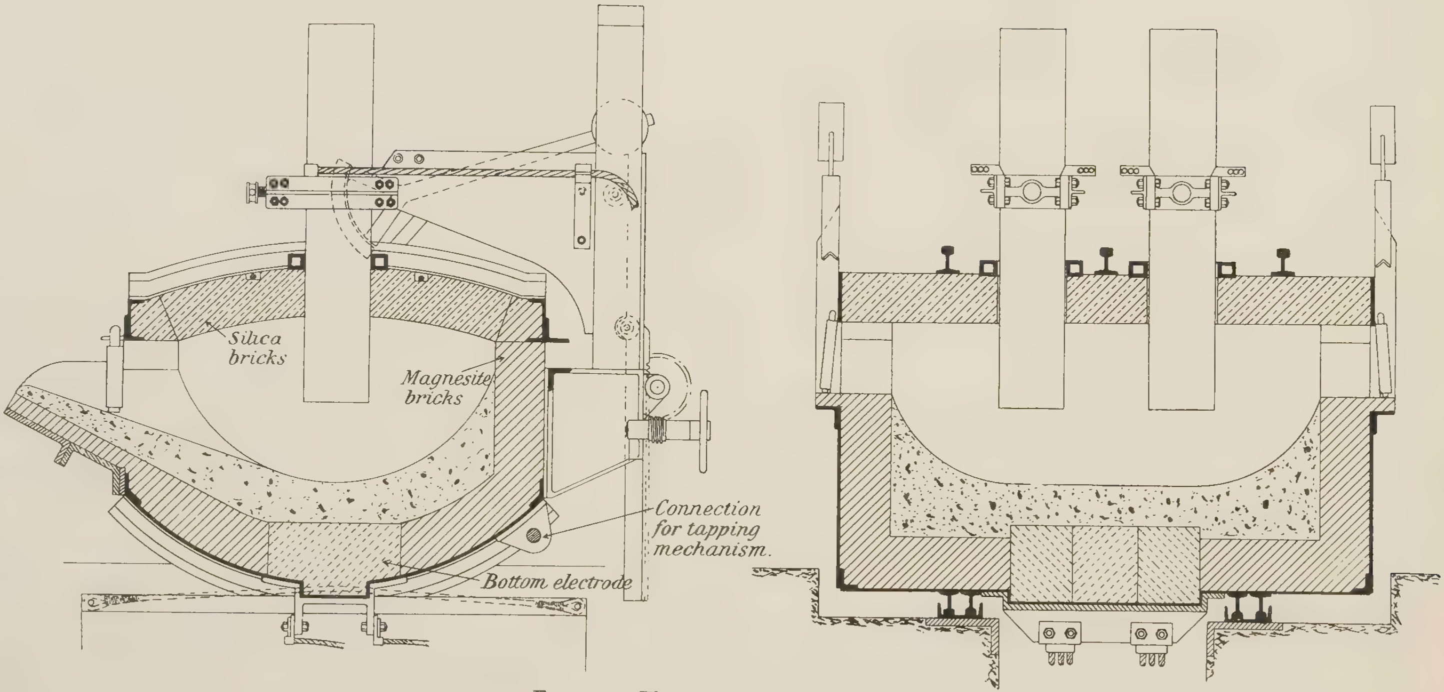


FIG. 244.—The Electro-metals Furnace.

roof and with a connection at the bottom for the return current, the arrangement being shown in Fig. 244. The furnace is built up of cast iron or mild steel plates, and at the bottom is bolted a casting, into which the electrode of carbon or graphite is set with a special cement mixture to ensure a good electrical contact. This electrode is then built in with magnesite bricks, and above this is an unbroken lining of dolomite or magnesite, similar to the ordinary basic open-hearth furnace. The two top electrodes are connected to each phase of a two-phase supply, so that two independent arcs are formed. The electrodes are regulated either by hand or by automatic regulators as required. The roof is removable, and is composed of silica bricks.

Owing to most power supply stations generating either two or three-phase high tension current, a two-phase furnace of this type offers the advantage of using the current supply without the need of rotary converters. If two-phase high-tension current is available, the voltage is transformed to a suitable tension, *i.e.* 65 volts, by means of 2 single-phase transformers (Fig. 245 (*a*)). If three-phase

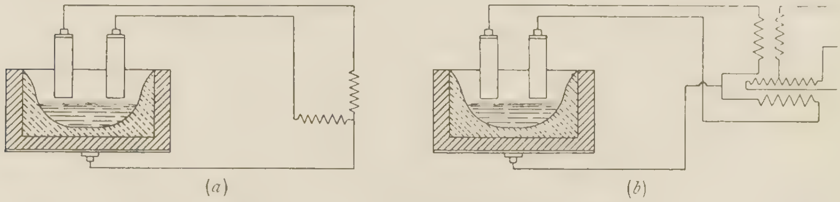


FIG. 245.—Diagrams of Connections: Electro-metals Furnace.

current is available, the supply is transformed to two-phase at 65 volts by means of Scott's arrangements of connections (Fig. 245 (*b*)).

By reason of the arcs being independent of each other, should one be broken the other will probably still be maintained, and consequently the violent fluctuations which at times occur in the power supply with arcs in series with each other, are not so severe with this type of furnace.

This furnace is used for refining molten metal from Bessemer converters or open-hearth furnaces, or for melting and refining from cold materials.

THE KELLER ELECTRIC FURNACE

Description of the Furnace.—The special feature of the Keller furnace is the conducting hearth, which is made of reinforced clay. Iron bars about 1 inch to $1\frac{1}{4}$ inches diameter are spaced vertically in the bottom of the furnace about 1 inch to $1\frac{1}{4}$ inches apart, and fitted securely at their lower ends into a casting bolted to the shell of the furnace. Round these rods is rammed hot magnesite clay, thus forming a refractory hearth which is a conducter when cold, by reason of the iron bars. The conducting bottom of the furnace is connected to one of the poles of the electrical supply. As will be seen from Fig. 246, which gives a sectional elevation of the furnace, the current is supplied to the furnace by carbon electrodes, and the arrangement is in other respects similar to the Girod furnace previously described in this chapter.

The following particulars are given[1] of an 8–10 ton furnace installed at the Holtzer Steel Works, Unieux, fed with molten steel from a Martin furnace. The electric furnace is fitted with 4 movable electrodes, 2 of each of which

[1] "Iron and Coal Trades Review," vol. 78, p. 961.

are in parallel. These electrodes are supported from revolving arms by flexible bars, and pass through the furnace roof. They can, therefore, be raised or lowered as required and swung away from the furnace when new electrodes are required to be fitted, or when it is desired to remove the roof. The furnace itself is mounted on trunnions and is provided with hydraulic tipping gear.

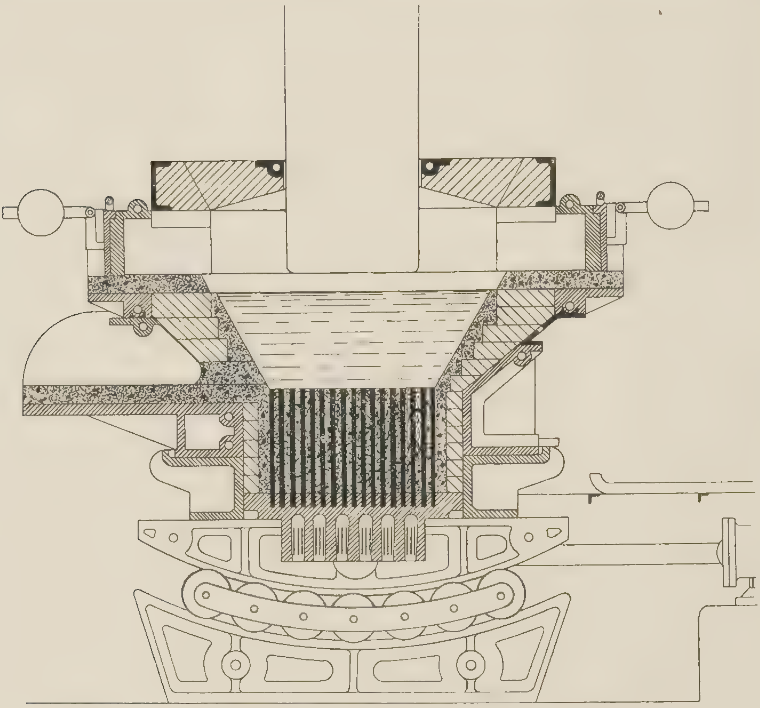


FIG. 246.—The Keller Furnace.

The molten charge of 7 tons 8 cwts. is refined in $2\frac{3}{4}$ hours with an average power load of 750 killowatts, at an energy consumption of 275 k.w. hours per ton. The compositions of the metal charged and the steel produced are :—

Molten charge—0·15% C ; 0·007% P ; 0·06% S.
Finished steel—0·044% C ; 0·008% P ; 0·009% S.

The consumption of each of the 4 electrodes (16 inches square) is $\frac{3}{4}$ inch per hour, costing 28*s.* per heat or 3*s.* 3*d.* per ton of steel refined. To work the above furnace, 1 melter and 3 labourers are required.

THE LEVOZ ELECTRIC FURNACE

Description of the Furnace.—The Levoz furnace is intended for refining only. It is built in cylindrical form of iron or steel plates, the top being in the form of a dome, and the whole is mounted upon a pair of trunnions, thus giving the furnace the appearance of a Bessemer converter. Fig. 247 gives sectional elevations of the furnace. The casing is lined with refractory material consisting

of magnesite bricks in the lower or crucible part, and siliceous bricks in the upper part. The electrodes, of which there may be one or more of the same polarity, are arranged above the bath and pass through the dome-shaped top, which at that part is water-cooled. Electrodes of opposite polarity to the above are built into the side walls as shown, and are in electrical contact with the upper portion of the bath, from which they are separated by a partial conducting material such as dolomite and tar, pitch or carbon, or a mixture of magnesite and furnace ashes. The furnace is provided with openings in the side at right angles to the trunnions, for charging the materials, slagging, and teeming.

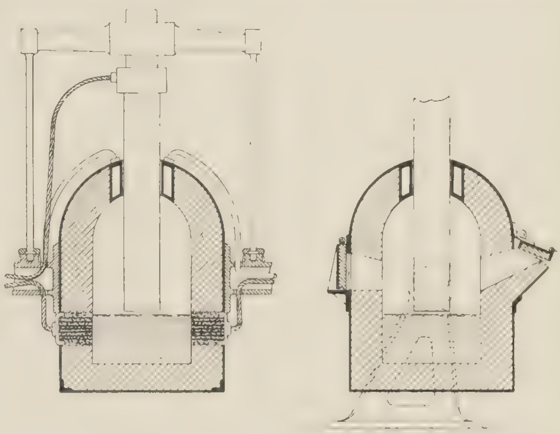


FIG. 247.—The Levoz Furnace.

The metal is melted in a cupola and tapped into the furnace, where the refining takes place and additions are made similar to the methods followed in other refining furnaces. The necessary circulation of the metal in the bath is said to be set up by a kind of inverse cementation from molecule to molecule, the inception of which is facilitated by the difference of density existing between refined and unrefined metal.

THE NATHUSIUS ELECTRIC FURNACE

Description of the Furnace.—Plate IX shows the general arrangement of a 12-ton Nathusius furnace and equipment. There are three vertical carbon electrodes above the bath, arranged at the apexes of an equilateral triangle, and connected to the three outer ends of the secondary circuit of a three-phase generator or transformer. Steel electrodes are also built into the bottom of the furnace, and these are connected to the inner ends of the secondary circuit of the same three-phase generator or transformer. The furnace is cylindrical, and mounted on rollers and cradle, the tipping being performed by means of an electric motor. There are three doors—one between every two top electrodes—through which the bath may be inspected. The bottom electrodes are steel castings built into the furnace bottom from below and covered with a layer of fireproof material rammed down for forming the bath. The whole furnace except the roof, is lined with dolomite, the roof being built with dinas, quartz, or other bricks having a high percentage of alumina.

The top electrodes are suspended by ropes from pulleys overhead, and previous to tilting they are rapidly raised by means of quick-acting motors, and are lowered again immediately the furnace is brought back to its working position. When it is necessary to renew the electrodes, the holders can be drawn sideways from the furnace. The electrical apparatus, measuring instruments, and regulating devices are quite separate from the furnace, and fitted in an enclosure where they are protected from dust and heat, and from which the working of the furnace can be controlled.

Fig. 248 shows diagrammatically the electrical connections of the furnace. The three inner ends of the secondary circuit of the generator or transformer are kept separate so that the point of junction is transferred to the bath itself. The top and bottom electrodes have a continually varying polarity, the current flowing from one top electrode to the others, from one bottom electrode to the others, and from each top electrode to each bottom one. The bath is, therefore, heated by the surface currents, the currents flowing through the bath, and the bottom currents.

It is claimed that the current distribution over the bath section, as given by this type of furnace, sets up rotating fields round each stream line, which causes

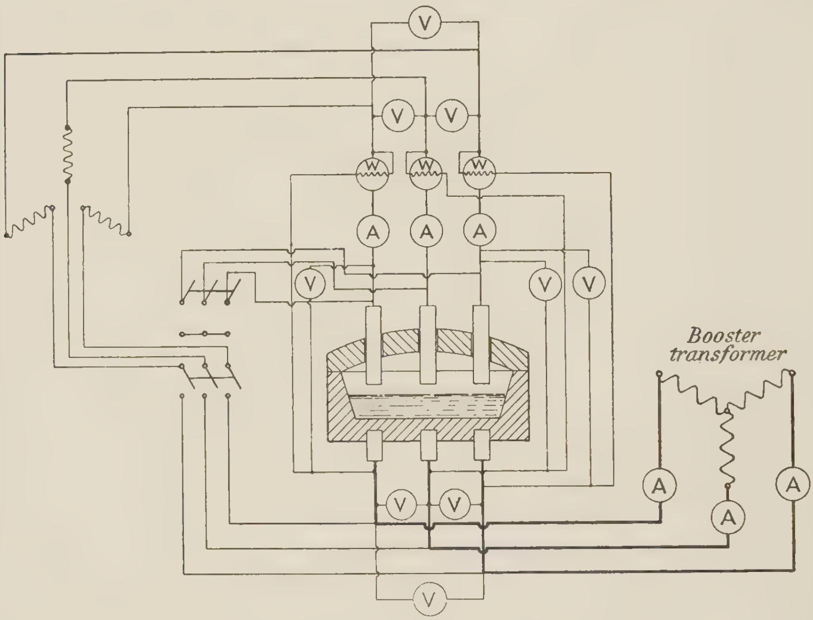


FIG. 248.—Electric Circuit for Nathusius Furnace.

a complete stirring up of the bath and leads to a thorough mixing of the metal. It is also claimed that with current flowing from each of its main heating centres, a more rapid heating of the bath is obtained than in furnaces where the arcs pass only between the top electrodes, or through the bath from top to bottom electrodes only. The current which flows between the bottom electrodes can be increased in strength by means of a specially built generator, or with the aid of a booster transformer.

Operation of the Furnace.—For the refining period of the running of the furnace, the heating of the slag by the strong arcs is aimed at, but later, during the deoxidising period, the strong overheating of the slag is no longer necessary, and, consequently, the energy of the surface arcs is brought lower down into the bath by means of the booster transformer connected to the bottom electrodes. Should it be desirable to allow the furnace charge to stand after the refining and deoxidising period has been completed, the equivalent heat lost by radiation can be supplied by cutting out the top electrodes and allowing current to circulate only between the bottom ones, producing a resistance heating in the bath.

Working Costs.—Cost per ton for refining molten open-hearth steel in a 5-ton Nathusius furnace, given by the inventor :—

	shillings.
Additions—	
Ores, 55 lbs. @ 29*s*. 2*d*. per ton	0·72
Lime, 66 lbs. @ 12*s*. per ton	0·36
Sand, 6·6 lbs. @ 2*s*. per ton	0·03
Fluorspar, 8·8 lbs. @ 26*s*. 2½*d*. per ton	0·11
Petroleum coke @ 38*s*. per ton	0·12
Deoxidising materials—	
Ferro-manganese (60 %), 13·2 lbs. @ 158*s*. per ton	0·95
Ferro-silicon (75 %), 2·2 lbs. @ 310*s*. per ton	0·31
Aluminium, 1·1 lb. @ £67 per ton	0·67
Refractory materials—	
Roof (cost, £12 10*s*., lasts 100 heats)	0·50
Crushed magnesite, 8·8 lbs. @ 50*s*. per ton	0·20
Crushed fire-clay, 8·8 lbs. @ 15*s*. per ton	0·06
Basic material, 33 lbs. @ 34*s*. per ton	0·51
Crushed fire-brick, 8·8 lbs. @ 17*s*. 6*d*. per ton	0·06
Electrodes—	
12·54 lbs. @ £14 10*s*. per ton	1·65
Holder	0·09
Wages—	
6 men	1·80
Current—	
250 k.w. hours @ 0·36*d*. per unit	7.50
Depreciation and interest—	
10 % depreciation and 5 % interest on outlay of £5000	1·70
Management charges and royalty—not included	—
Cost per ton for refining	17·33

CHAPTER XLIII

RESISTANCE FURNACES

It is only intended to give brief descriptions of three furnaces which have been constructed on the principle of heating by resistance, in which the current is supplied to the bath by other means than that adopted with induction furnaces described in Chapter XL. If properly applied, resistance heating is in all probability the most efficient. It yet remains to be seen whether the furnaces described will prove economical and efficient in practice.

The Helberger Electric Crucible Furnace

Description of the Furnace.—The charge in the Helberger furnace is melted in a crucible in which heat is generated by its resistance, and transmitted

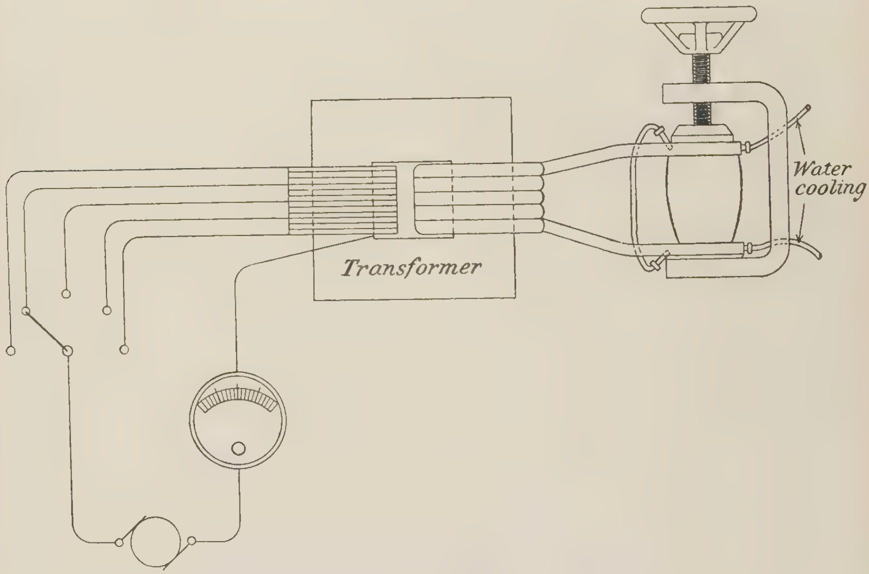


Fig. 249.—Electric Circuit for Helberger Furnace.

by conduction to the charge of metal. The apparatus comprises an alternating current transformer (which may be connected to either single-phase or polyphase circuits and at any normal voltage and frequency), connected to the secondary side of which are two specially designed water-cooled holding devices for gripping the plumbago or graphite crucible at the top and bottom. Fig. 249 represents diagrammatically the electric circuits. The transformer and furnace form a complete piece of apparatus, and since the instruments and switchgear are

mounted on the same stand, the complete arrangement can be placed in any position to which cables carrying the current may be brought.

Fig. 250 is a photograph of a furnace of about 220 lbs. capacity; the largest size of furnace made will melt 5 cwts. of steel.

The crucible is placed between the holding devices, and the upper one is clamped firmly on to the crucible as shown, the actual contact being made on carbon surfaces. Encircling the crucible are two fire-clay doors, which completely surround the active circuit, and thus retain the heat. The upper holding mechanism only covers the crucible round the rim; the contents of the crucible therefore can be examined at any time, and additions readily made to the

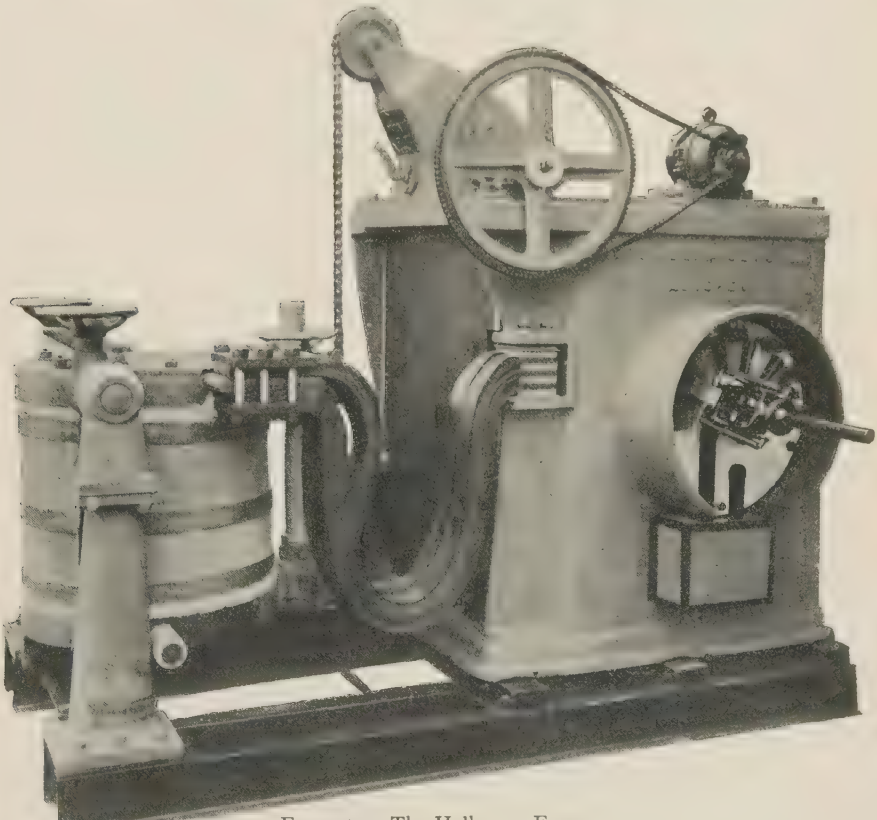


FIG. 250.—The Helberger Furnace.

charge. By means of the regulating switch, which is on the primary side of the transformer, the current in the secondary circuit can be varied through a considerable range, and the time of melting accelerated or retarded as required.

Operation of the Furnace.—It is found that less current is used when the crucible and its charge are cold than when hot, and for this reason the transformer equipment is adopted, since it gives more economical results than direct current with resistances.

In the case of the smaller furnaces, the charge is poured from the crucible by hand-tipping gear, but with the larger type the tipping is performed by an electric motor mounted on the same stand as the furnace.

To melt 220 lbs. of steel, a consumption of 100 to 150 kilowatt hours is required, which is equivalent to from 1020 to 1530 kilowatt hours per ton. Assuming that power can be purchased at the rate of 0·3*d.* per unit, the cost of melting (power only) is therefore from £1 5*s.* 6*d.* to £1 18*s.* 3*d.* per ton.

Each crucible lasts 10 to 12 heats.

The Hering Electric Furnace

Description of the Furnace.—In the Hering Furnace, the heat is produced by the passage of current through the bath in a special manner. If an electric current is passed through a bath or column of molten metal which is constricted in cross-sectional area so that the current density is raised to a certain point, the metal carrying the current contracts, or becomes "pinched." The effect of this on the metal is to set up pressure, which may become so great that a break may occur in the circuit. This "pinch effect" is made use of in the Hering furnace to transmit heat to the bath and to set up the circulation of the metal required for efficient melting and refining.

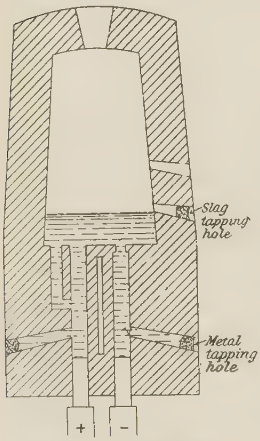


FIG. 251.—The Hering Furnace.

The arrangement of the furnace will be seen from the accompanying Fig. 251. The vertical type of furnace consists of a refractory dome-shaped chamber containing the hearth, and at the top of the dome is an opening for charging the materials. At the bottom of the hearth are two or more vertical holes, which terminate at their lower ends in contact with electrodes connected to the electrical supply, the number of the electrodes and holes being determined by the electrical supply on which the furnace is to be worked. The electrodes are water-cooled where they connect up to the furnace. The furnace is also arranged in another design with the metal columns inclined; by this means less hydrostatic pressure is required in the columns to ensure the transmission of heat throughout the bath.

The "pinch effect" is secured by properly proportioning the cross-sections of the columns with respect to the current traversing them. A side column is provided for further stimulating the circulation of the metal by making its cross-section different from that of the columns, thus setting up a difference of pressure, and the same result can be achieved by restricting the opening at the top of one of the columns as shown in the figure. The columns are made conical, with the large end at the top, so that when the furnace is shut down with metal in the columns, the columns of metal will not pull apart when they solidify. The columns are surrounded by a tube, or partially surrounded by a rod or plate extending the length of the columns, made of a material which conducts at a high temperature—carborundum, etc.—so that if the metal column is ruptured, the circuit will not be broken. An air space is also provided between the columns to ensure that current will not pass through the furnace wall between the columns.

Operation of the Furnace.—When starting the furnace, either molten metal is poured in, which fills up the vertical holes at the base, or a casting (preferably of the same material as the steel to be produced) is inserted, extending downward in the holes so that the ends may be in contact with the electrodes, and the top bridged over, insuring a complete circuit. The heat is produced in these metal columns by the resistance offered to the flow of current passing through them from the electrodes, and when molten, the material is charged

into the furnace through the opening at the top of the dome. The heat generated in the columns of metal is transferred to the bath by means of the "pinch effect," which causes the molten metal to flow up through the central axis of the columns, and the hydrostatic pressure will then cause it to flow downwards at the circumference of the columns.

The metal is tapped from a hole near the base of the columns, or from a spout at the bottom of the hearth. The slag is tapped through a hole situated on the slag line above which air may be drawn into the furnace to complete the combustion of the unburned gases given off from the charge in the hearth.

The Igewsky Electric Furnace

Description of the Furnace.—In the Igewsky furnace, the heat is generated in the lining of the furnace and transmitted to the bath by radiation and conduction. The furnace is in the form of a hollow cylinder lined with refractory material, and is rotated on rollers about its axis. The arrangement of the furnace is shown in Fig. 252. The current is led to contact plates fitted to the inside of the fixed frame, and from these, brass plates (which are connected to iron plates set radially in the brickwork) collect the current. The passage of current through the iron plates and the intervening brickwork, generates the heat which is utilised for the melting and refining of the metal in the interior of the furnace. The lining used is either acid or basic, but since the electrical conductivity of the latter has been found to be about twice as great as that of the former, the conductivity of heat is also more, and the result is a certain loss of energy.

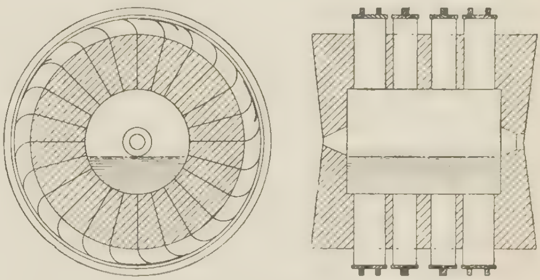


FIG. 252.—The Igewsky Furnace.

A 1-ton furnace in operation, has 36 iron electrode plates built into the lining, each 44 inches long × 12 inches wide. The interior of the furnace is 2 feet 6 inches diameter and 4 feet long, the lining (which is an acid one) being 12 inches thick. The current used is 600 amperes at 550 volts. The furnace is rotated by an electric motor at a speed of 2 revs. per minute.

Operation of the Furnace.—When starting up the furnace, either a coke fire is placed inside or a gas flame is inserted, and the brickwork heated until a temperature of about 300° C. is attained. The interior of the lining is then coated with a solution of hydrate or carbonate of soda, which forms a thin conducting layer for the current, and by reason of its incandescence when heated, assists in the radiation of the heat.

The inventor states that the cost of installation is small, and the consumption of power does not exceed 1000 k.w. hours per ton of steel produced. With larger furnaces, this consumption would probably be somewhat less. The cost of repairs and the labour required for working the furnace are about the same as for other electric furnaces. Heating the furnace above 1700° C. results in the destruction of the lining.

The following are some of the advantages claimed for the furnace :—

(1) High voltage may be employed.
(2) The possibility of using any form of current ordinarily employed.
(3) Compactness.

CHAPTER XLIV

THE CHEMICAL REACTIONS IN THE ELECTRIC FURNACE

THE chemical changes which take place in the process of steel making and refining in the Electric Furnace, are similar to those in kindred processes. The heating agent, being free from sulphur, the process is well adapted for making better quality steel. Other functions peculiar to the electric furnace which influence in some measure the chemistry of the process are :—

(*a*) The higher temperatures than those obtainable in other steel-making processes, and their influence in refining.

(*b*) A more easily maintained non-oxidising atmosphere in the furnace than in other processes.

The reactions in the process may be divided into two parts :—

(1) The oxidation period.

(2) The deoxidation period.

The Oxidation Period.—This part of the refining commences when the melting of the solid charge is completed, or as soon as the molten metal is charged, depending upon whether cold or molten charges are being worked. The oxidation is carried out by means of additions of iron ore or rolling mill scale, to which is added lime to form a basic slag (the furnaces themselves being usually basic lined), and under the heat of the furnace, the silicon, manganese, carbon, phosphorus, and sulphur are more or less oxidised. If the carbon content is fairly high, more than one oxidising slag may be required before the carbon is reduced to the required amount. The oxidation favours the removal of the phosphorus in the basic slag, in the form of phosphoric acid (P_2O_5), and the following analyses taken during the oxidation period of the charge in a 3-ton Girod furnace, show clearly the reduction in the impurities which takes place. The metal charged was partially refined open-hearth steel of the analysis given. It will be noticed that the sulphur is also partially eliminated during this period, but the main consideration is the elimination of the phosphorus.

Oxidation period :—

	Sample No.	C.	Si.	Mn.	P.	S.
Charge	1	0·15	tr.	0·54	0·034	0·054
After adding 22 lbs. ore .	2	0·14	,,	0·40	0·021	0·048
,, ,, 33 ,, .	3	0·14	,,	0·34	0·016	0·044
,, ,, 55 ,, .						
Just before slagging . . .	4	0·10	,,	0·29	0·008	0·046

When the oxidation and its accompanying dephosphorisation has been carried out sufficiently, the slag is poured off. If this slag were allowed to remain during the second period, the deoxidising materials would cause a return of the phosphorus in the slag to the steel, since the phosphoric acid in the slag is not stable. With the object of rendering this slagging operation unnecessary, Mr. E. Humbert patented, in 1909, a process whereby the addition of a

reducing material to the oxidising slag converts the phosphate into a stable phosphide.

The Deoxidation Period.—It is during the deoxidising period, which immediately follows the oxidising period, that the bulk of the sulphur is removed from the charge. The deoxidising slag is formed by the addition of lime, sand, and fluorspar, and the materials used for deoxidation are petroleum coke and ferro-silicon. The necessary carbon addition is made at the beginning of this period in the form of petroleum coke, pieces of carbon electrodes, or coal, and a study of the various charges which follow, will show that the carbon content thus formed remains practically constant during this part of the process.

The molten slag, which on dissolving the ferrous oxide formed, is black, becomes whiter as the iron from it returns to the bath. An examination of the colour of the slag throughout the deoxidation period enables the furnaceman to determine the progress of deoxidation. When the slag becomes white, it is not necessarily indicative of the removal of sulphur from the steel, but rather, it shows the reduction of ferrous oxide in the slag, and some little time elapses before the sulphur is reduced from the metallic sulphides formed.

The destruction of the ferrous oxide is essential for deoxidation and desulphurisation. From the researches[1] carried out by Dr. Th. Geilenkirchen on a Héroult furnace, and Professor B. Osann on a Röchling-Rodenhauser furnace, both arrived at the conclusion that the removal of sulphur in the electric furnace is due to the formation of calcium sulphide. If, however, calcium sulphide is present in the slag, it has a great tendency to oxidise and form $CaSO_4$ which if formed, would act upon the iron as follows, and the sulphur would pass back into the steel bath :—

$$CaSo_4 + 4Fe = FeS + 3FeO + CaO.$$

The oxidation of calcium sulphide is claimed to be impossible in the Héroult furnace, first by reason of the strongly reducing nature of the slag, and second because the atmosphere in the furnace is reducing. The conversion of iron sulphide into calcium sulphide is supposed to be due to the presence of calcium carbide, which forms spontaneously in the furnace under the action of the electric arc. The operation of desulphurisation is described as follows :—The strongly reducing slag formed on the surface of the bath, first deoxidises the bath in such a way that the metallic oxides pass into the slag and are reduced to metal, which returns into the steel bath, while the calcium carbide is oxidised to lime and carbon monoxide. After this reaction is completed (*i.e.* when the slag and the bath contain no longer any metallic oxides), the reducing slag acts on the metallic sulphides and reduces them in forming calcium sulphide :—

$$FeS + C + CaO = CaS + Fe + CO.$$
$$MnS + C + CaO = CaS + Mn + CO.$$

The slag formed is white, and disintegrates to a white powder on exposure to the atmosphere.

The above investigations confirm Prof. Osann's experiments on a 1-ton Röchling-Rodenhauser furnace. He found that sulphur was not removed if the deoxidiser (ferro-silicon) was replaced by ferro-manganese. Further, if the slag contained considerably more than 2 per cent. of iron, the removal of sulphur was found to be unsatisfactory. Prof. Osann concludes that an iron content in the slag prevents desulphurisation of the steel bath. The following results are given of the working of a hard charge :—

[1] "Iron and Coal Trades Review," vol. 78, p. 230.

Experiment in 2200-lb. Röchling-Rodenhauser Furnace.

	Analysis of Bath. C	Si	Mn	P	S
Analysis of bath after treatment with mill scale	0·105	0·016	0·204	0·012	0·069
Added 11 lbs. of 50 per cent. ferro-silicon (egg size) and 33 lbs. of coal. Slag made from 22 lbs. of lime and 8·8 lbs. of fluorspar. When slag was fluid the analysis of bath was	1·07	0·092	0·248	0·020	0·044
11 lbs. of lime, 4·4 lbs. of 50 per cent. ferro-silicon (pea size) and 4·4 lbs. of fluorspar thrown on to slag	1·07	0·096	0·234	0·013	0·028
Since slag was still dark, another addition of 2·2 lbs. of 50 per cent. ferro-silicon and 2·2 lbs. of fluorspar was made. Colour of slag became lighter	1·07	0·19	0·263	0·015	0·016
Again, 4·4 lbs. of 50 per cent. ferro-silicon and 4·4 lbs. of fluorspar added. Slag now white. Furnace tilted	1·05	0·25	0·263	0·016	0·008

Composition of last slag :—

SiO_2	CaO	FeO	MnO	S	Fe
28·66	43·3	2·59	0·70	0·45	2·22

As illustrative of the changes which occur during the oxidising and deoxidising operations, the analysis of the slag probably indicates more clearly the progress of the refining, and Table XCII (p. 469), giving the working of a 5-ton charge in a Röchling-Rodenhauser furnace, shows the reactions which take place during the oxidation and deoxidation periods.

The desulphurisation carried out during the deoxidising period may also be seen from the following analysis taken during the refining of a Girod furnace charge of 7050 lbs. of molten open-hearth metal. The preceding oxidation period of this same charge has been already given on page 466.

Deoxidation period :—

	Sample No.	C	Si	Mn	P	S
After adding 52·8 lbs. of petroleum coke and 110 lbs. of refining slag	5	0·50	tr.	0·26	0·010	0·034
After adding 88 lbs. of refining slag	6	0·50	tr.	0·26	0·010	0·038
" 66 lbs. of refining slag	7	0·49	tr.	0·27	0.010	0·026
" 19·8 lbs. of ferro-manganese	8	0·50	tr.	0·49	0·011	0·026
" 2·2 lbs. of powdered petroleum coke and 11 lbs. of ferro-silicon	9	0·52	0·07	0·52	0·015	0·026
After adding 11 lbs. of ferro-silicon	10	0·52	0·14	0·52	0·012	0·018
" 8·8 lbs. of ferro-manganese	11	0·56	0·14	0·61	0·015	0·010
Final sample	12	0·56	0·14	0·62	0·015	0·010

It would appear from the investigations made, that the formation of calcium carbide plays an important part in the desulphurising reactions, although considerable difference of opinion exists as to the way in which the reactions occur. Mr. E. H. Saniter,[1] to whom the steel making industry owes much for his investigations into the question of the removal of sulphur from steel, doubts

[1] "Journal Iron and Steel Institute," 1910, II, p. 206.

TABLE XCII

WORKING OF A 5-TON MOLTEN CHARGE IN A RÖCHLING-RODENHAUSER FURNACE.[1]

Period	Time.	Sample No.	Bath C	Bath Si	Bath Mn	Bath P	Bath S	Slag CaO	Slag SiO_2	Slag FeO	Slag Fe	Slag MnO	Slag MgO	Slag P	Slag S
			Percentage Analysis of bath.					Percentage Analysis of slag.							
Oxidation period.	0 0. Molten charge	1	0·06	0·02	0·49	0·06	0·065	—	—	—	—	—	—	—	—
Oxidation period.	0 20	2	0·07	0·02	0·28	0·025	0·054	38·5	9·0	24·9	28·2	6·8	4·9	0·71	0·54
Oxidation period.	0 40	3	0·07	0·02	0·21	0·022	0·049	40·0	8·4	24·1	28·3	5·7	4·4	0·645	0·69
Oxidation period.	1 0	4	0·06	0·03	0·12	0·018	0·053	43·0	8·25	21·1	25·2	4·7	5·0	0·428	0·45
Oxidation period.	1 20	5	0·06	0·03	0·12	0·015	0·057	48·6	8·4	21·4	24·0	4·2	4·0	0·428	0·50
Oxidation period.	1 40	6	0·07	0·02	0·12	0·0145	0·053	48·5	8·6	20·25	23·6	4·0	4·5	0·47	0·55
Slagging off, recarburising, and formation of second slag.	2 0. Added 220 lbs. of coke and 28·4 lbs. of ferro-silicon	7	0·06	0·02	0·12	0·012	0·048	—	—	—	—	—	—	—	—
Slagging off, recarburising, and formation of second slag.	2 40 Added 13·2 lbs. of ferro-spiegel; Added 28·4 lbs. of 50 % ferro-silicon to slag	8	1·26	0·02	0·15	0·015	0·028	66·3	15·0	1·5	1·7	0·25	4·3	0·048	1·22
Reduction period.	2 50. Added 4·4 lbs. of 80 % ferro-manganese	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Reduction period.	3 0. Added 15·4 lbs. of 50 % ferro-silicon to slag	9	1·39	0·15	0·21	0·016	0·022	64·4	18·1	1·3	1·9	0·25	4·2	0·048	1·25
Reduction period.	3 15	10	1·30	0·21	0·24	0·013	trace	64·4	18·1	1·3	1·9	0·25	4·2	0·048	1·25

[1] "Journal Iron and Steel Institute," 1909, I, p. 312.

whether calcium carbide has anything to do with desulphurisation. It is at any rate evident that fluorspar is in some measure responsible for the reactions which occur, as when used both in the open-hearth and electric furnaces, it is accompanied by a reduction of sulphur in the steel. A continuance of the investigations into the subject will no doubt establish definitely the actions which take place, and probably result in economical and rapid methods of desulphurisation in most, if not all, of the types of steel-making furnaces employed.

CHAPTER XLV

COMPOSITION OF CHARGES EMPLOYED, AND ANALYSES AND USES OF STEEL PRODUCED IN THE ELECTRIC PROCESS

THE manufacture of steel in the electric furnace can be classified under three heads :—

(1) Steel made from pure raw materials, melted and "killed" only, as in the crucible furnace.

(2) Steel made from cold materials melted and refined, producing steel of superior quality to that of the raw materials charged.

(3) Refined steel produced from blown converter metal or partially refined molten open-hearth steel.

Steel produced under heading (3) is the result of the duplex process, *i.e.* the combination of the Bessemer converter and electric furnace or the open-hearth and electric furnace. Descriptions of the materials used in the duplex processes appear in Chapter XXXVII, and reference should be made to this chapter for descriptions and details of charges refined in the electric furnace.

By far the largest proportion of steel made in the electric furnace from cold materials is made from steel scrap. Pig iron in large proportions in the cold charge is seldom used, as it prolongs the operation, because of the increased presence of carbon and other impurities in the iron, which take longer time to remove, and consequently more electric power, as well as higher working costs. The usual practice is to charge steel scrap of such analysis as will give as nearly as possible when melted, the required carbon content to the finished steel. By this means the refining period is reduced to a minimum, and the cost of working thereby diminished. In cases where high carbon tool steel is produced, and scrap tool steel is not available, pig iron and pure iron bar cuttings are used, mixed in such proportions as will give as nearly as possible the desired steel. The process then is practically one of melting and "killing" only, as in the crucible process.

The following table gives the power required to produce 1 ton of steel, and shows clearly the saving in power in working with scrap steel :—

Kilowatt-hours necessary for the production of 1 *ton of steel* (*Rodenhauser-Schoenawa*).[1]

	K.w. hours.
From cold pig iron	1500
„ liquid pig iron	1100–1200
„ cold pig iron and cold scrap .	900–1300
„ liquid pig iron and cold scrap .	600–1000
„ cold scrap	300–900

[1] "Journal Iron and Steel Institute," 1911, II, p. 221.

Uses of Electric Steel.—With the development of the electric process, more and more applications are found for the steel produced, and it is impossible to give a definite list of the uses to which this steel can be put. Not only is the electric furnace now used for making high-speed and carbon tool steels similar to those manufactured in the crucible furnace, but it is also being used for the production of special alloy steels and steel castings. (The large furnaces working under the duplex process are being used for refining steel for rail ingots, etc.)

The limitation set upon the use of steel from the electric furnace is that of cost, and consequently, only higher grades of steel, which command a fair price, are made in the electric furnace when charged with cold raw materials. There is no question as to the quality of the steel produced, and frequently the steel made by the electric furnace is of higher quality than that made by the older types of furnaces producing steel for the same purpose.

From the above it will be seen that, so far, the electric furnace may be considered as a competitor of the crucible furnace, small Bessemer converter, and small open-hearth furnace, and its ultimate partial or complete displacement of these older types of furnaces will depend mainly upon the comparative costs of manufacture of steel in each process. In Table XCIII is given a list of analyses of some of the steels which have been made in the electric furnaces referred to. They, however, in no way indicate the limits of analyses of steels which it is possible to make in any one of the types of furnaces mentioned.

Materials used in the Charges.—The quality of the materials used and the composition of the charges vary within very wide ranges, and depend not only upon the raw materials available and the quality of steel to be produced, but also upon the type of furnace employed. In furnaces where scrap charges are commonly used, care should be exercised in the selection of the scrap, and where this is purchased from an open market, some method should be adopted for its classification and supply. The pig iron used with the scrap in the charge should be of good quality and as free as possible from phosphorus and sulphur.

Typical analyses of suitable pig irons are given in Table XI, page 14.

Tool Steel Charges and Analyses.—For the production of tool steel in the electric furnace, probably the most economical method is to simply melt and "kill" high quality raw materials, or, in other words, use the furnace as a large crucible heated electrically. It has been by means of the use of high-grade raw materials that the crucible furnace has maintained its position as the most suitable furnace for the manufacture of high-grade tool steel, and it is by following these methods that the electric furnace is most likely to compete commercially with the crucible furnace. It must not be forgotten, however, that the electric furnace has the advantage over the crucible furnace in that considerable refining of the materials can be carried out in it, consequently less expensive raw materials can be used in the electric furnace and still produce equally as good steel as would be obtained from the crucible furnace using better quality materials. Provided that the steel from each process proves as economical in working, the deciding factor in the use of high quality materials in the electric furnace simply melted and "killed," or lower-grade materials melted and refined, will be in the cost of production.

Following are two typical charges[1] of materials used in a 1-ton Kjellin furnace for the production of carbon tool steel having the following analysis:—C, 0·4 to 2·0 per cent.; Si, 0·12 per cent., Mn, 0·34 per cent.; P, 0·014 per cent.; S, 0·012 per cent.

[1] "Journal Iron and Steel Institute," 1906, III, pp. 397–9.

TABLE XCIII

ANALYSES AND TESTS OF STEEL MADE IN ELECTRIC FURNACES

No.	Purpose for which steel is required.	Type of furnace.	Analysis. C %	Si %	Mn %	P %	S %	Mechanical tests. Tenacity. Tons per sq. in.	Elastic limit. Tons per sq. in.	Elongation.	Reduction of area. %
1	Tool steel	Kjellin	0·89	0·27	0·3	0·015	0·005	47	27·4	10% on 7·87″	33
2	,,	Hiorth	1·02	0·112	0·301	0·021	0·008	—	—	—	—
3	,,	Frick	0·77	0·15	0·40	0·013	0·015	53·1	—	16·6	46
4	Steel castings	Héroult	0·12	0·037	0·18	0·005	trace	—	—	—	—
5	,,	Girod	0·53	0·474	0·275	trace	0·017	35·7–40	—	—	—
6	,,	Stassano	0·207	0·236	0·421	0·027	0·043	26·15	—	—	—
7	Loco wheel tyres	Girod	0·52	0·78	0·19	0·015	0·018	50·0	—	11·1% on 7·87″	25·5
8	Structural steel	,,	0·13 to 0·25	0·08 to 0·26	0·55 to 0·88	trace to 0·018	0·014 to 0·02	26·2 to 38·1	—	31 to 23·5% on 7·87″	65·6 to 49·1

1. Paper read by Dr. Kjellin before the American Electrochemical Society, May, 1909.
2. "Transactions American Electrochemical Society." vol. xviii, p. 200.
3. "Foundry Trade Journal," 1909, p. 150.
5, 7, and 8. "Stahl und Eisen," Aug. 3rd, 1911.
6. "Journal Iron and Steel Institute," 1911, II, p. 224.

Charge 1.—Production of carbon tool steel from high-grade pig iron, scrap, and briquettes, in the Kjellin furnace.

Materials charged :—

White pig iron	1457 lbs.
Steel scrap	439 ,,
Briquettes	220 ,,
Ferro-silicon (50 % Si)	17 ,,
Ferro-manganese (80 % Mn). . .	15 ,,
Aluminium :	1 oz.

Progress of heat :—

Time.		Units consumed.
5.30.	Charging $\frac{2}{3}$ of pig iron	—
6.0	. . . .	67·5
6.30	. . . .	76·25
7.0.	Charging remaining $\frac{1}{3}$ of pig iron and the scrap	82·5
7.30	. . . .	85·0
8.0.	Clear melted	83·75
8.30.	Briquettes added	82·50
9.0	. . . .	82·50
9.30.	Briquettes added	82·50
10.0	. . . .	82·50
10.30.	Briquettes added	82·50
11.0	. . . .	82·50
11.30	. . . .	82·50
12.0.	Ferro-silicon and ferro-manganese added . . . . . . Tapped.	73·75
	Total	1046·25

Time taken, $6\frac{1}{2}$ hours.

Power consumption, 1046·25 k.w. hours.

Analysis of white pig iron (Herräng) : C, 4·0 per cent. ; Si, 0·15 per cent. ; Mn, 0·18 per cent. ; P, 0·012 per cent. ; S, 0·01 per cent.

Analysis of briquettes : Fe, 59·0 per cent. ; S, 0·01 per cent. ; P, 0·006 per cent. ; SiO_2, 11·0 per cent. ; CaO, 2·5 per cent. ; Al_2O_3, 0·5 per cent.

Charge 2.—Production of carbon tool steel from high-grade pig and scrap in the Kjellin furnace.

Materials charged :—

White pig iron	914 lbs.
Steel scrap	1372 ,,
Ferro-silicon (50 % Si)	4·5 ,,
Ferro-manganese (80 % Mn) . . .	6·5 ,,
Aluminium	1 oz.

The time taken was 5 hours, and the power consumption 793 k.w. hours per ton of steel produced.

Analysis of pig iron, same as in Charge 1.

High Grade Steel Casting and Ingot Charges.—Apart from the manufacture of tool steel, the electric furnace is applied to the manufacture of steel for steel castings and high grade steel ingots. The material commonly used is steel scrap, with or without a small proportion of pig iron to give the desired carbon content. The following are typical charges :—

Charge 3.—The following[1] is typical of Girod furnace practice, producing steel castings.

Materials charged—

Pig iron	580 lbs.
Turnings	330 ,,
Scrap iron and steel	1010 ,,
Return scrap from foundry	935 ,,
Lime	130 ,,

Ferro-manganese, ferro-silicon, and aluminium added as required, depending upon the grade of steel to be produced.

The charging takes about 1 hour, and the melting and refining about 5 hours, for a charge of 3300 lbs.

A typical analysis of the steel castings produced is—

C, 0·53 % ; Si, 0·474 % ; Mn, 0·275 % ; P, trace ; S, 0·017 %,

giving a tenacity of 35·7 to 40 tons per square inch.

Charge 4.—Héroult Furnace Charge. The following charge is for a $2\frac{1}{2}$-ton Héroult furnace working under favourable conditions, producing low carbon steel ingots.

Commenced heat	5.40 p.m.
Charge—	
Scrap	2 tons 10 cwts.
First slag—	
Lime	90 lbs.
Iron ore	45 ,,
Slag removed	8.30 p.m.
Second slag—	
Lime	90 lbs.
Fluorspar	45 ,,
Ferro-silicon	22 ,,
Ferro-manganese	7 ,,
Coke dust	4 ,,
Pig iron (added at 8.50 p.m.)	55 ,,
Aluminium	1 lb.

Finished	9 p.m.
Total time	3 hours 20 mins.
Total units	1320
Units per ton	552
Weight produced	2 tons 7 cwts. 2 qrs. 15 lbs.

Analysis	C	Si	Mn	P	S
	0·12	0·037	0·18	0·005	trace per cent.

[1] "Foundry Trade Journal," 1910, p. 150.

Charge 5.—Typical cold scrap charge[1] worked in a 1-ton Stassano Furnace producing mild steel castings.

Materials charged—

Cast steel scrap	550 lbs.
Sheet steel scrap	770 ,,
Turnings	330 ,,
,, (very rusty)	154 ,,
Hematite pig	62 ,,
Ferro-silicon	$7\frac{1}{2}$,,
Ferro-manganese	7 ,,
Lime	66 ,,
Calcium carbide	$8\frac{3}{4}$,,

Analysis of steel produced (average of 8 charges)—

C, 0·207 %; Si, 0·236 %; Mn, 0·421 %; P, 0·027 %; S, 0·043 %.

Tensile strength of castings—26 tons per square inch.

[1] "Journal Iron and Steel Institute," 1911, II, p. 224.

PART V

COSTS AND LABOUR

CHAPTER XLVI

COMPARISON OF COSTS OF LIQUID STEEL

1. *Produced by the same process.*
2. *Produced by different processes.*

THE following tables are prepared from the costs of steel recorded in the preceding chapters. Table XCIV gives the cost of steel suitable for steel castings

TABLE XCIV

COSTS PER TON OF LIQUID STEEL PRODUCED IN CRUCIBLE FURNACES, FOR STEEL CASTINGS [1]

No.	Items.	Types of crucible furnaces.			Gas-fired, regenerative.	
		Coke-fired. Huntsman.	Coke-fired. 4-pot holes.	Coke-fired. Forced draught. "Radio."	"Ordinary form" Siemens.	"New form" Siemens.
1	Cost of furnace	£900	£1200	£700	£3500 [2]	£2000
2	No. of furnaces	1	1	10	1	2
3	Output in tons per week	25	25	25	25	25
4	No. of shifts	2	1	1	2	2
5	No. of heats per shift	3	3	4	3	3
6	Size of crucibles used	75 lbs.	75 lbs.	85 lbs.	75 lbs.	75 lbs.
7	No. of crucibles in each melting hole	2	4	3	6	12
8	No. of melting holes	12	12	10	4	2
9	Maximum weight of castings	15 cwts.	30 cwts.	20 cwts.	15 cwts.	15 cwts.
10	Kind of fuel used	Coke	Coke	Coke	Coal gas (prod.)	Coal gas (prod.)
11	Price of fuel per ton	23*s.* 6*d.*	23*s.* 6*d.*	15*s.*	10*s.*	10*s.*
		£ *s.* *d.*	£ *s.* *d.*	£ *s.* *d.*	£ *s.* *d.*	£ *s.* *d.*
12	Depreciation and interest	2 3	3 0	1 9	8 9	5 0
	Working costs:—					
13	Repairs	4 6	5 0	5 0	6 6	5 6
14	Fuel	2 1 1	1 9 4	1 10 0	15 0	12 0
15	Crucibles	19 0	19 0	1 15 6	19 0	19 0
16	Labour + 50% for management	1 16 9	1 10 0	1 9 4	1 18 10	1 16 9
17	Power	—	—	1 3	—	—
18	Raw materials, including additions and loss	4 2 11	4 2 11	4 2 11	4 2 11	4 2 11
	Total cost of liquid steel	£9 6 6	£8 9 3	£9 5 9	£8 11 0	£8 1 2

[1] For full details of each cost, see chapters relating to each type of furnace.
[2] This type of furnace is more profitable when used for larger outputs.

produced in different Crucible Furnaces. The materials used in the charges are of the same money value in each case, and the loss in each furnace is taken as being the same. The "Ordinary form" Siemens Furnace is better adapted for larger outputs, thereby reducing the cost of steel per ton. The Forced Draught Furnace, on the other hand, is more suitable for smaller outputs.

In Table XCV the cost of steel for carbon and high-speed tools is given. The operating costs differ only slightly from those in Table XCIV for making steel for ordinary castings. The labour and fuel costs are a little higher, but the principal item of cost is material. Thus, for high speed steel, the materials of which the charges are composed may cost from £50 to £200 per ton.

TABLE XCV

COSTS PER TON OF LIQUID STEEL PRODUCED IN CRUCIBLE FURNACES, FOR TOOL STEEL[1]

No	Item.	Type of furnace used—ordinary coke-fired Huntsman.			
		Carbon tool steel.	High speed tool steels.		
			A grade.	B grade.	C grade.
1	Cost of furnace.	£1200	£1200	£1200	£1200
2	Output in tons per week . .	25	25	25	25
3	No. of shifts	2	2	2	2
4	No. of heats per shift . . .	3	3	3	3
5	Average capacity of crucibles.	55 lbs.	55 lbs.	55 lbs.	55 lbs.
6	No. of crucibles in each melting hole	2	2	2	2
7	No. of melting holes . . .	16	16	16	16
8	Maximum weight of ingots .	15 cwts.	15 cwts.	15 cwts.	15 cwts.
9	Usual ,, ,, .	50 lbs.	50 lbs.	50 lbs.	50 lbs.
10	Kind of fuel used	Coke	Coke	Coke	Coke
11	Price per ton of fuel . . .	28*s*.	28*s*.	28*s*.	28*s*.
		£ *s*. *d*.	£ *s*. *d*.	£ *s*. *d*.	£ *s*. *d*.
12	Interest and depreciation on furnace	3 0	3 0	3 0	3 0
	Working costs—				
13	Repairs	4 9	4 9	4 9	4 9
14	Fuel	4 4 0	4 18 0	4 18 0	4 18 0
15	Crucibles	13 6	13 6	13 6	13 6
16	Labour + 50% for management	2 7 7	2 7 7	2 7 7	2 7 7
17	Raw materials	13 3 3	74 12 5	75 13 11	150 12 10
	Total cost of liquid steel per ton	£20 16 1	£82 19 3	£84 0 9	£158 19 8

[1] For full details of each cost, see Chapter X.

Table XCVI shows that the surface-blown plants can be adapted to almost any size of steel foundry. For ordinary and high quality castings of large and small weights, it is equally well adapted. Even double the highest output given in the table, namely 320 tons per week, could be produced by duplicating the plant, and castings correspondingly heavier than 20 tons could be procured if four vessels were being "blown" at one time. If, however, the bulk of the castings produced were each over 20 tons in weight, it would be advisable to instal larger converters and fewer of them, or open-hearth furnaces. With reference to the small outputs given in the table, namely, 18 tons per week, the price per ton of steel in the ladle is nearly 20 per cent. higher than that of the larger plants.

TABLE XCVI

COMPARATIVE COSTS PER TON OF LIQUID STEEL FROM SURFACE-BLOWN CONVERTER PLANTS, CAPABLE OF PRODUCING FROM 320 TO 18 TONS PER WEEK, AND STEEL CASTINGS FROM 20 TONS WEIGHT TO 1 LB. EACH [1]

No.	Items.	Bessemer Acid Surface-blown Converters.									
		2 tons capacity working 10 hours per day.						1-ton converters.			½-ton converter.
1	Cost of Converter equipment	£10,000	£6000	£3500	£10,000	£6000	£3500	£1950	£1950	£1950	£1100
2	Output in tons per week .	320	160	84	220	110	60	42	30	18	18
3	Number of heats per day per converter	14	14	14 [2]	10	10	10 [2]	14 [2]	10 [2]	6 [2]	12 [2]
4	Size of converters . . .	2 tons	2 tons	2 tons	2 tons	2 tons	2 tons	1 ton	1 ton	1 ton	½ ton
5	Number of converters . .	4	2	1	4	2	1	1	1	1	1
6	Number in operation . .	2	1	1	2	1	1	1	1	1	1
7	Maximum weight of castings	20 tons	7 tons	4 tons	20 tons	7 tons	4 tons	30 cwts.	15 cwts.	15 cwts.	7 cwts.
8	Minimum ,, ,,	1 lb.	1 lb.	1 lb.	1 lb.	1 lb.	1 lb.	a few ozs.	a few ozs.	a few ozs.	a few ozs.
		£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
9	Depreciation and interest .	0 1 9	0 2 1½	0 2 3½	0 2 3	0 2 6	0 3 3	0 2 8½	0 3 9½	0 6 4	0 3 7
	Working costs :—										
10	Repairs	0 4 0	0 4 6	0 5 0	0 5 0	0 5 6	0 5 9	0 7 6	0 8 6	0 9 6	0 8 6
11	Fuel	0 3 11½	0 4 6	0 4 6	0 4 6	0 4 9	0 4 9	0 5 7½	0 6 0	0 6 6	0 6 2
12	Labour + 50% for management	0 5 2½	0 6 7	0 7 6	0 6 6½	0 7 11	0 9 0	0 7 7½	0 9 0	0 11 0	0 12 0
13	Power	0 1 3	0 1 3½	0 1 4	0 1 4	0 1 4	0 1 4½	0 1 4	0 1 6	0 1 8	0 1 5
14	Raw materials, including additions and loss	3 13 8	3 13 8	3 13 8	3 13 8	3 13 8	3 13 8	3 13 8	3 13 8	3 13 8	3 17 6
	Total cost of liquid steel per ton in ladle	£4 9 10	£4 12 8	£4 14 3½	£4 13 3½	£4 15 8	£4 17 9½	£4 18 5½	£5 2 5½	£5 8 8	£5 9 2

[1] For full details of each cost, see chapters relating to each type of furnace.
[2] Working 3 days per week.

Table XCVII gives a comparison of costs of steel for castings made in a few types of electric furnaces. The cost of scrap given in the cold charges differs in each case, but the molten pig iron for the charges which are refined, is taken at 50*s.* per ton.

TABLE XCVII

COMPARATIVE COSTS PER TON OF LIQUID STEEL PRODUCED IN ELECTRIC FURNACES FOR STEEL CASTINGS[1]

No.	Items.	Girod furnace.		Röchling-Rodenhauser furnace.		Héroult furnace.	
		Melting cold scrap.	Refining molten charge.	Melting cold scrap.	Refining molten charge.	15 ton furnace refining molten charge for rails, etc.	2½ ton furnace melting cold scrap for castings.
1	Cost of equipment	£2000	£2000	£2350	£3540	£6000	£2000
2	No. of furnaces	1	1	1	1	1	1
3	Capacity of furnaces	2½ tons	2½ tons	2 tons	5 tons	15 tons	2½ tons
4	No. of heats per 24 hours	4	10	4	8	12	4
5	No. of shifts	2	2	2	2	2	2
6	Output in tons per week	50	125	40	200	1000	50
		£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
7	Depreciation and interest	2 5	1 0	3 6	1 1	4½	2 4
	Working costs—						
8	Repairs	12 0	4 0	2 9½	2 8	9	2 6
9	Power	1 5 0	8 6	1 2 8	7 3	3 1½	19 9
10	Electrodes	4 0	1 7	—	—	1 6	5 10
11	Labour	4 9	2 5	6 3	2 1	9	6 0
12	Raw materials	2 17 0	3 4 6[2]	2 12 6[3]	3 4 0[2]	3 4 6[2]	2 18 9
13	Fluxes and additions	2 5	1 7	2 6	2 6	3 9	4 6
14	Management (50 % of labour)	2 4	1 2½	3 1½	1 0½	4½	3 0
	Cost of liquid steel per ton	£5 9 11½	£4 4 9½	£4 13 4	£4 0 7½	£3 15 1½	£5 2 8

[1] For full details of each cost, see chapters relating to each type of furnace.
[2] Cost of molten pig iron is taken at 50*s.* per ton.
[3] This cost of raw materials should be increased, when comparing it with the others given in Table.

Royalty charges, ladle heating and repairing, and water cooling of electrodes, are not included in the above costs.

Cost of power is taken at 0·3*d.* per k.w. hour throughout.

Table XCVIII gives the comparative costs of steel made by different processes for the same classes of steel castings, such as automobile and other like intricate castings. The processes and furnaces can be employed also for medium quality castings.

TABLE XCVIII

COMPARATIVE COSTS OF STEEL PRODUCED IN DIFFERENT FURNACES FOR STEEL CASTINGS.[1]

OUTPUT—20 TO 40 TONS PER WEEK

No.	Items.	Crucible furnaces. Coke fired. Ordinary.	Crucible furnaces. Coke fired. Forced draught.	Crucible furnaces. Gas fired. Ordinary.	Crucible furnaces. Gas fired. New form.	Bessemer converters. Surface blown. 1-ton plant.	Bessemer converters. Surface blown. ½-ton plant.	Open-hearth furnace. Siemens New form.[2]	Electric furnace. Héroult. Melting cold scrap.
1	Cost of furnace and equipment	£1200	£700	£3500	£2000	£1950	£1100	£1800	£2000
2	Output in tons per week	25 tons	25 tons	25 tons	25 tons	42 tons	18 tons	25 tons	50 tons
3	Number of furnaces	—	—	—	—	1	1	1	1
4	,, heats per shift	3	4	3	3	14[3]	12[3]	2	2
5	,, shifts	1	1	2	2	1	1	1	2
6	Capacity of furnace	—	—	—	—	1 ton	½ ton	2 to 3 tons	2 to 3 tons
7	,, crucibles	75 lbs.	85 lbs.	75 lbs.	75 lbs.	—	—	—	—
8	Number of crucibles in each hole	4	3	6	12	—	—	—	—
9	,, melting holes	12	10	4	2	—	—	—	—
10	Maximum weight of castings	30 cwts.	20 cwts.	15 cwts.	15 cwts.	30 cwts.	7 cwts.	35 cwts.	35 cwts.
11	Minimum weight of castings	a few ozs.	a few ozs.	a few ozs.	a few ozs.	a few ozs.	a few ozs.	a few lbs.	a few ozs.
12	Kind of fuel used	coke	coke	Producer gas	Producer gas	—	—	Producer gas	Electricity
		£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
13	Depreciation and interest on capital	0 3 0	0 1 9	0 8 9	0 5 0	0 2 8½	0 3 7	0 4 6	0 2 4
14	Repairs	0 5 0	0 5 0	0 6 6	0 5 6	0 7 6	0 8 6	0 5 10	0 2 6
15	Fuel	1 9 4	1 10 0	0 15 0	0 12 0	0 5 7½	0 6 2	0 8 0	—
16	Crucibles	0 19 0	1 15 6	0 19 0	0 19 0	—	—	—	—
17	Electrodes	—	—	—	—	—	—	—	0 5 10
18	Power	—	0 1 3	—	—	0 1 4	0 1 5	—	0 19 9
19	Labour and part management	1 10 0	1 9 4	1 18 10	1 16 9	0 7 7½	0 12 0	0 18 0	0 6 0
20	Raw materials								
21	Fluxes	4 2 11	4 2 11	4 2 11	4 2 11	3 13 8	3 17 6	3 15 6	3 3 3
22	Ferro-manganese and ferro-silicon								
23	Management, 50% of labour	—	—	—	—	—	—	—	0 3 0
	Total cost per ton of liquid steel	£8 9 3	£9 5 9	£8 11 0	£8 1 2	£4 18 5½	£5 9 2	£5 11 10	£5 2 8[4]

[1] For full details of each cost, see chapters relating to each type of furnace.
[2] The cost is based on 2 heats per day. If worked fully for 24 hours, 3 heats could be obtained, thus reducing the cost.
[3] Working 3 days per week.
[4] Exclusive of royalty charges, etc. See Table XCVII.

TABLE XCIX

COMPARATIVE COST OF STEEL PRODUCED IN DIFFERENT FURNACES FOR STEEL CASTINGS. OUTPUTS FROM 50 TO 320 TONS PER WEEK[1]

No.	Items.	Bessemer converters.				Open-hearth.	Electric.	Molten charges.
		Surface-blown.		Bottom-blown.		Oil Fired.	Girod.	Röchling Rodenhauser.
		2 tons.	2 tons.	2 tons.	2 tons.	15 tons.	$2\frac{1}{2}$ tons.	5 tons.
1	Cost of furnace and equipment	£6,000	£10,000	£8,000	£11,000	£10,000	£2,000	£3,540
2	Output in tons per week	160 tons	320 tons	160 tons	320 tons	255 tons	125 tons	200 tons
3	Number of furnaces	2	4	2	4	1	1	1
4	,, heats per shift	14	14	14	14	3	5	4
5	,, shifts	1	1	1	1	2	2	2
6	Capacity of furnace	2 tons	2 tons	2 tons	2 tons	15 tons	$2\frac{1}{2}$ tons	5 tons
7	Maximum weight of castings	7 ,,	20 ,,	7 ,,	20 ,,	12 ,,	35 cwt.	4 ,,
8	Minimum ,, ,,	1 lb.	1 lb.	1 lb.	1 lb.	a few lbs.	1 lb.	1 lb.
9	Kind of fuel used	—	—	—	—	oil	—	—
		£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
10	Interest and depreciation on capital	0 2 $1\frac{1}{2}$	0 1 9	0 2 $4\frac{1}{2}$	0 1 11	0 3 0	0 1 0	0 1 1
11	Repairs	0 4 6	0 4 0	0 4 8	0 4 6	0 4 6	0 4 0	0 2 8
12	Fuel	0 4 6	0 3 $11\frac{1}{2}$	0 4 6	0 3 $11\frac{1}{2}$	0 7 5	—	—
13	Electrodes	—	—	—	—	—	0 1 7	—
14	Power	0 1 $3\frac{1}{2}$	0 1 3	0 2 9	0 2 7	—	0 8 6	0 7 3
15	Labour and part management	0 6 7	0 5 $2\frac{1}{2}$	0 6 9	0 5 $3\frac{1}{2}$	0 5 5	0 2 5	0 2 1
16	Raw materials							
17	Fluxes	3 13 8	3 13 8	3 13 8	3 13 8	3 12 6	3 6 1[2]	3 6 6[2]
18	Ferro-manganese and ferro-silicon							
19	Management, 50% of labour	—	—	—	—	0 1 9	0 1 $2\frac{1}{2}$	0 1 $0\frac{1}{2}$
	Total cost of liquid steel per ton	£4 12 8	£4 9 10	£4 14 $8\frac{1}{2}$	£4 11 11	£4 14 7	£4 4 $9\frac{1}{2}$	£4 0 $7\frac{1}{2}$

[1] For full details of each cost, see chapters relating to each type of furnace.
[2] Cost of molten pig iron is taken at 50*s.* per ton.

TABLE C

COMPARATIVE COSTS OF STEEL PRODUCED IN DIFFERENT FURNACES FOR INGOTS, OUTPUT FROM 1,000 TO OVER 10,000 TONS PER WEEK[1]

No.	Items.	Bessemer converters.		Open-hearth.				Electric.
		Basic. 24 tons.	Basic. 10 tons.	Basic. 75 tons. Molten charge.	Basic. 40 tons. Cold charge.	Basic. 35 tons. Cold charge.	Talbot. 200 tons. Molten charge.	Héroult. 15 tons. Molten charge
1	Cost of furnaces and plant	£200,000	£90,000	£200,000	£50,000	£40,000	£47,700	£6,000
2	Output of furnaces per week	10,500 tons	3,780 tons	5,000 tons	1,472 tons	2,100 tons	1,200 to 1,400 tons	1,000 tons
3	Number of furnaces	4	4	5	3	2	1	1
4	,, furnaces in operation	3	3	4	3	2	1	1
5	,, heats per furnace per 24 hrs.	28	24	2 to 2½	2 to 2½	4 to 5	5 to 6	12
6	,, shifts	2	2	2	2	2	2	2
7	Capacity of furnace	24 tons	10 tons	75 tons	40 tons	35 tons	200 tons	15 tons
8	Kind of fuel used	—	—	Producer gas	Producer gas	Producer gas	Producer gas	—
		£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
9	Interest and depreciation on capital	0 9 6 includes fluxes and ferro-manganese	0 1 3½	0 2 6	0 2 6	0 1 5	0 2 8	0 0 4½
10	Repairs		0 3 6	0 2 9	0 1 6	0 2 0	0 2 0	0 0 9
11	Fuel		0 0 5	0 3 5	0 4 3	0 2 5½	0 2 3	—
12	Electrodes		—	—	—	—	—	0 1 6
13	Power		0 1 2	—	—	—	—	0 3 1½
14	Labour and part management		0 2 6	0 3 9	0 3 4	0 2 3	0 3 0	0 0 9
15	Raw materials	2 10 0	2 10 0	2 10 10	2 10 0	2 10 2	2 14 0	3 4 6
16	Fluxes	—	0 2 1	0 1 0	0 0 6	0 0 4	Included in raw materials	0 3 9
17	Ferro-manganese	—	0 2 0	0 1 6	Ferro-manganese and loss included in raw materials	0 1 6		
18	Loss of material during process	0 7 6	0 7 6	Loss included in raw materials		Included in raw materials		Included in raw materials
19	Management	—	—	0 1 6	0 0 5	0 1 6	0 1 6	0 0 4½
	Total	3 7 0	3 10 5½	3 7 3	3 2 6	3 1 7½	3 5 5	3 15 1½
20	Less value of slag	0 3 6	0 3 6	—	—	—	—	—
	Total cost per ton of liquid steel	£3 3 6	£3 6 11½	£3 7 3	£3 2 6	£3 1 7½	£3 5 5	£3 15 1½

[1] For full details of each cost, see chapters relating to each type of furnace.

Table XCIX compares the Bessemer, Open-hearth, and Electric processes for the production of steel up to 320 tons per week. The costs are based on maximum outputs from each plant. The electric furnace costs do not include items of cost, such as royalty charges, and ladle heating and repairing.

In Table C are compared the Bessemer, Open-hearth, Talbot, and Electric processes in producing steel ingots. The pig iron in the molten charges is taken at 50*s*. per ton. The most remarkable cost is that of the 35-ton furnace melting cold charges.

American Bessemer Converter and Open-hearth Furnace Steel Costs compared.

About five years ago[1] a most careful and laborious investigation was undertaken by Commissioner Herbert Knox Smith of the U.S.A., for the Bureau of Corporations investigating steel costs in typical plants, with the object of establishing some definite record of the actual costs of items of expenditure in the production of steel rails and billets in Bessemer and Open-hearth plants, together with records of the profits and losses of the various Steel Companies engaged in such manufactures. The investigations were most exhaustive, and made by a large staff of men "under the direction of an expert steelman," who examined numerous accounts from the various manufacturers who together produced 93 per cent. of the total rails in the United States during the period of five years under consideration.

In view of the value of the information collected, for comparison with corresponding items of costs of steel produced by the various processes of steel manufacture summarised in this chapter, the following Tables, CI, CII, CIII, and CIV, have been prepared from the Commissioner's figures.

TABLE CI

Cost of producing Bessemer Pig Iron (all Districts), during 1902-1906

Total tons produced—51,902,699

Items of Cost.	Price per ton.	Cost per ton of pig iron.
	£ s. d.	£ s. d.
Nett total metallic mixture	0 16 6½	1 10 5
Coke	0 14 0½	0 16 2½
Limestone	—	0 1 9½
Labour[2]	—	0 3 2½
Steam	—	0 0 6
Materials in repairs and maintenance	—	0 0 8
Supplies and tools	—	0 0 6½
Miscellaneous and general works' expenses	—	0 1 2
General expense	—	0 1 6
Refining and renewals	—	0 0 9
Depreciation	—	0 1 7½
	Total	£2 18 4½

[1] "Iron Age," vol. 82 (1908), p. 1987.

[2] The item of labour does not include, for much of the tonnage, the labour of unloading raw materials and producing steam, which some of the companies include in the cost of raw materials and in the item "Steam."

TABLE CII

COST OF PRODUCING BESSEMER STEEL RAILS DURING 1902–1906
TONS PRODUCED—14,020,303

Items of Cost.	Price per ton.	Cost per ton of rails.
	£ s. d.	£ s. d.
Bessemer pig iron[1]	3 0 6	3 8 7½
Waste	8 1½	
Labour	—	0 8 3
Manganese, etc.	—	0 4 1½
Fuel	—	0 1 5½
Steam	—	0 2 7
Moulds	—	0 0 7½
Rolls	—	0 0 8½
Materials in repairs and maintenance	—	0 1 9
Supplies and tools	—	0 1 1½
Miscellaneous and general works expenses	—	0 2 1½
General expense	—	0 0 7
Depreciation	—	0 0 8
	Total	£4 12 7½

Operating costs in conversion from pig iron = £1 12s. 1½d.

[1] The difference in price of pig iron from that given of Bessemer pig iron in Table CI, is due to variations in the cost of the excess of tonnage, and to freight on some of the iron.

TABLE CIII

COST OF PRODUCING LARGE BESSEMER AND OPEN-HEARTH STEEL BILLETS DURING 1902–1906

Tons produced during 5 years.	Large Bessemer Billets, 17,908,033.	Large Basic O.H. Billets, 13,422,740.
Items of Cost.	Per ton.	Per ton.
	£ s. d.	£ s. d.
Pig iron and scrap	2 19 9	2 17 5
Waste	0 8 1½	0 6 10
Cost of pig iron and scrap in billets	3 7 10½	3 4 3
Variation in cost of ingots[2]	0 1 6	0 0 3
Labour	0 4 11	0 6 7
Manganese and fluxes	0 1 6½	0 2 5½
Fuel	0 1 6½	0 3 11
Steam	0 2 0½	0 1 6½
Moulds	0 0 8	0 0 8½
Rolls	0 0 1	0 0 2
Materials in repairs and maintenance	0 1 1½	0 1 11½
Supplies and tools	0 0 8½	0 1 6
Miscellaneous and general works' expenses	0 1 2½	0 1 7½
General expense	0 0 5	0 0 6½
Open-hearth rebuilding	—	0 1 0
Depreciation	0 0 5	0 0 5½
Totals	£4 4 0½	£4 6 11½

[2] This variation is chiefly due to the fact that only a portion of the ingots made were used for large billets, and the average price at which this portion was used differed by that much from the average cost of all ingots.

TABLE CIV

COMPARATIVE COSTS, SELLING PRICES, AND PROFITS IN THE PRODUCTION OF STEEL BILLETS DURING 1902–1906

Item.	Year.	Bessemer.		Open-hearth.		Average selling prices of Bessemer and O.H. steel Billets.
		Cost per ton.	Profit per ton.	Cost per ton.	Profit per ton.	
		£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
1	Highest (1903)	5 3 11½	—	6 1 0	—	5 18 11½
2	Lowest (1905)	3 12 7½	—	3 16 0	—	4 5 9½ (1904)
3	Average (1906)	—	0 15 5½	—	1 2 7	Average during period.
4	Lowest (1906)	—	0 2 7	—	1 0 5	£5 1 3

2. The cost of £3 12*s.* 7½*d.* was merely the cost for steel sold, but about 9 times as much more steel was made and used by the same company at a cost of £3 16*s.* 1*d.*, which is perhaps a fairer, and certainly a more significant figure.

German Steel Costs.—Table CV is prepared from costs given by Mr. F. Grassman [1] for manufacturing steel in the processes enumerated. The items of cost are of interest when compared with those in the other tables.

TABLE CV

BASIC STEEL. COST PER TON OF INGOTS

No.	Items of Cost.	Basic Bessemer.	Daelen Pszczolka.	Talbot.	Bertrand. Thiel.	O. H. Scrap Process.
		£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
1	Raw materials for 1 ton	2 16 0	2 15 0	2 15 0	2 15 0	2 10 1
2	Loss in converting	0 8 9	0 6 1½	—	—	0 5 1
3	Cost of other materials :—					
	Dolomite	0 1 0	0 0 7	0 1 0	0 1 0	0 1 2½
	Tar	0 0 2½	0 0 1	0 0 1	0 0 1	0 0 1
	Ore	0 0 0½	0 0 9½	0 6 0	0 6 0	0 0 3½
	Coke	0 0 3½	0 0 2½	0 0 1	0 0 1	0 0 1
	Coal for gas	0 0 0½	0 2 2½	0 3 6	0 3 6	0 4 0
	Coal for steam	0 2 2	0 2 0	0 0 9½	0 0 9	0 0 7
	Lime	0 2 3	0 0 9½	0 0 9½	0 0 9½	0 0 9½
	Graphite, wood, aluminium	0 0 1½	0 0 1	0 0 1	0 0 1	0 0 1
	Ladle stoppers, etc.	0 0 4½	0 0 4½	0 0 4½	0 0 4½	0 0 4½
	Ingot moulds	0 0 6	0 0 6	0 0 6	0 0 6	0 0 6
	Ferro-manganese	0 2 0	0 2 0	0 2 9½	0 2 9½	0 2 0
	Miscellaneous repairs and stores materials	0 1 6½	0 2 6	0 2 10	0 2 6½	0 2 6
4	Wages	0 2 0	0 4 0	0 4 0	0 4 0	0 4 6
5	Salaries	0 0 6	0 0 6	0 0 6	0 0 6	0 0 6
6	Interest and depreciation	0 1 1	0 1 5	0 1 8½	0 1 2½	0 1 5
	Totals . . . £	3 18 10½	3 19 2	4 0 0½	3 19 2½	3 14 1
	Value of bye-products £	0 4 0	0 0 6	0 0 9½	0 2 0	0 0 6
	Actual net cost of ingot iron £	3 14 10½	3 18 8	3 19 3	3 17 2½	3 13 7

[1] "Stahl und Eisen," vol. 21, p. 1021.

CHAPTER XLVII

THE ASSEMBLING OF STEEL WORKS' COSTS

THE various items which go to form the cost of steel require careful and regular assembling if they are to be of real service to the steel maker. Cumbersome methods are sometimes employed, involving considerable labour and giving only indifferent results. Steel works managers require, in concrete form, tabulated results to which they can refer quickly with the minimum of trouble.

To arrive at a summary of accurate costs, constant records must be kept of the weights of all materials which are received for and used in the manufacture of steel. No less important is the keeping of a careful record of all labour involved in the various operations, as well as of the power consumed for operating the furnaces and auxiliary plant, and for lighting. Standing charges, such as depreciation of plant, and interest on capital, and management expenses, can be definitely fixed at so much per ton of steel produced according to the output per week, or any other convenient period.

System of Keeping Costs.—Only those responsible for the final assembling of the costs need know what the various items of costs are provided the system is a good one. Complete and satisfactory results can be obtained without leakage of information, which manufacturers, as a rule, are anxious to avoid. In working such a system, it is necessary to observe definite rules while avoiding "red tape." The following are essential, and can be carried out readily.

1. All materials and stores which are issued from store in aid of steel manufacture, to be ordered on forms by a responsible charge hand or foreman, a duplicate being retained in order book.

2. All forms used for recording the various items of cost, to be so arranged that the minimum of labour is involved in entering the information required.

3. All daily records of materials, etc., used and steel produced, to be collected daily after being scrutinised and initialled by the steel plant manager or superintendent, are passed on to the cost clerk. Weekly records to be similarly dealt with.

4. The cost clerk to be supplied with a list of all the materials used in steel making, with the prices per ton, cwt., or lb. against each item.

5. A list of all the men employed on the steel plant, with the rate of pay or share of tonnage received, indicated against the name of each man, to be kept by the cost clerk. This list would include all auxiliary hands, such as those employed occasionally about the plant on repairs. This record is simply for reference, and to familiarise the cost clerk with the classification of labour and the rates paid against each class.

6. All labour records to be made by any of the accredited reliable checks, such as clocks, etc. These to be forwarded daily to the time clerk.

7. All items of cost to be reckoned at so much per ton of liquid steel in the ladle.

8. The total cost of steel produced during each week from say Monday morning until Saturday, to be ready for inspection by the following Tuesday morning of each week.

Methods adopted and Forms used to Secure the above Results.—Some allowance must necessarily be made in working any one system for various processes of steel manufacture, but the 8 rules given above are applicable to all, although the forms used require to be varied according to the process adopted.

In giving the details of costs of steel made by the Bessemer process, one may readily apply a similar or modified method to all the other processes, without setting forth the forms necessary for each of the other processes. The analysis of the cost of steel made by the Bessemer process is selected, as a greater number of items of cost appear in it than in any of the other processes.

Surface-blown Bessemer Steel Costs.

Items of Cost assembled.—

1. Raw materials used in actual manufacture.
2. Other materials used in aid of manufacture.
3. Fuel.
4. Power.
5. Labour.

The following items are added to the above :—

6. Depreciation and interest per ton of steel made.
7. Part charge of management expenses.

1. **Raw Materials used in Actual Manufacture.**—The following list of materials and prices to be kept in cost office. The prices to be adjusted as fresh purchases are made at different costs.

Pig iron.
Scrap steel, heavy.
" " light.
Ferro-manganese.
Spiegeleisen.
Ferro-silicon.
Ferro-chrome.
Nickel.
Limestone.
Fluorspar.
Aluminium.

While it is unnecessary for the cost clerk to have the analyses or any compositions of the materials with which he is dealing, it is, of course, understood that the usual analyses of all materials are made and recorded by the chemist or the metallurgist before any materials are accepted for use. In the case of pig iron and alloys, where different kinds are frequently used they are known under brand names to the cost department. These names are either painted on boards which are placed on the stacks of pig iron and other materials, or in some prominent way the classification of the materials is made known to the yardmen who handle the materials.

Forms for Recording the Materials used.—From the pig iron and scrap steel stocks in the yard (particulars of the weight of which are recorded in the raw materials ledger), charges are put on trucks and weighed on weighbridge before being raised to charging platform. The common way of setting the weighbridge arm to indicate the weight required per charge, and then adjusting

the weight of the load accordingly, is very simple, and saves time in making accurate measurements for each load on the truck. Where this is done carefully it is all that is required, but there is a liability to error unless the pig iron and scrap are weighed separately. The pig can be weighed in separate trucks, or after the weight of the pig has been acertained, the scrap can be added to the same truckload. The latter method is commonly employed when weighing small charges for the plant in question.

The forms on which the weights are checked, are fastened with a clip to a small board which hangs on the wall close to the weighbridge, and is printed as shown in Form I.

A B C Co., Ltd.
BESSEMER STEEL PLANT
FORM I
CUPOLA CHARGE SHEET

Shift Date

The following weights of materials to be included in each cupola charge to-day.

Signed

Materials.	Weight.	No. of charges to be entered in this column.
Pig iron *No. 1*	*6* cwts.	
,, ,, ...	cwts.	
Forged steel scrap, heavy .	cwts.	
,, ,, ,, light .	cwts.	
Scrap, rail ends	*4* cwts.	
Scrap, cast steel, heavy . .	cwts.	
,, ,, ,, light . .	*2* cwts.	
Limestone	*30* lbs.	
Fluorspar	*6* lbs.	
Coke	*1* cwt for first *4* charges and ¾ cwt for remainder.	
Coke bed	*10* cwts.	

To be handed to Foreman at end of shift.

The weight of the various materials intended to be used daily with each cupola charge, is entered up on the form by the charge-hand or foreman, and for every charge passed up on the lift to the charging stage a mark is made on the form, every 4th charge being marked with a diagonal line across the three previous lines, thus indicating that 4 cupola charges, which are required for one converter charge, have been raised to the cupola stage. At the end of the shift, the recorder hands the form to the foreman or superintendent, who enters the details on the converter charge sheet. A fresh form is issued to the night shift weighbridge man, if two shifts are being worked.

Form II is used for giving instructions to the chargeman at the physic cupola, heating furnace, or crucibles, according to the method adopted for melting or heating the additions for the charge. In large Bessemer plants where the ingots produced are usually of two or three qualities only, very few variations are required in the weight and character of the additions. In the case, however, of steel production for castings in miscellaneous steel foundries, many variations are made during the course of a shift to meet the requirements of the

orders on hand. It is, of course, the aim of the steel maker to produce steel with as few changes in the mixtures as possible.

The complete programme of charges for each day's campaign is usually prepared during the preceding afternoon.

A B C Co., Ltd.

BESSEMER STEEL PLANT

FORM II

PHYSIC ADDITIONS FOR CONVERTER CHARGES

Shift Date

Pig iron and scrap steel to be melted in physic cupola.
Ferro-alloys of Mn and Si to be heated to redness.
Other ferro-alloys to be melted in crucibles.

Materials.	Additions to charges.			
	Nos. *1, 2, 3, & 6.*	Nos. *4, 5, & 9.*	Nos. *7, 8, & 10.*	Nos. *11, 12, & 13.*
Pig Iron *No. 1* . . .	*3 cwts.*	*2 cwts.*	*3 cwts.*	*2½ cwts.*
,, *No. 2* . . .	*3 cwts.*	*½ cwt.*	*3 cwts.*	*2½ cwts.*
Scrap, cast steel, light.	*1 cwt.*	*1½ cwts.*	—	—
Ferro-manganese (80 %)	*50 lbs.*	*40 lbs.*	*45 lbs.*	*30 lbs.*
Spiegeleisen . . .	—	*50 lbs.*	—	—
Ferro-silicon (50 %) .	*25 lbs.*	*20 lbs.*	*20 lbs.*	*25 lbs.*
Ferro chrome . . .	—	—	—	—
Aluminium	*1 lb.*	*1½ lbs.*	*1 lb.*	*1½ lbs.*
Nickel	—	—	—	—

Coke used during shift . . . . cwts.
Limestone used during shift . . . . . ,,
Fluorspar ,, ,, ... ,,

To be handed to Foreman at end of shift.

Signed

The contents of Form II are as follows: In the columns giving the different charge numbers, all the charges shown in one column are supplied with the same amount of physic, according to the weights given. As it would add considerably to the labour and expense of production to weigh the fuel and fluxes used with the materials for each charge, without any corresponding advantage, the total weights of fuel and fluxes used during the day are taken, and the average weight per charge entered up accordingly.

Having provided for the record of the raw materials and physics for the charges, it is now necessary to ensure an accurate check of the weight of the metal melted in the cupola, and also blown in the converter. The man who does the "blowing," known as "the blower," may have entire charge of the plant, or he may be responsible for the "blowing" only. It is, however, usual to give "the blower" the charge of the cupola plant as well, so that the temperature of the metal, etc., may be in accordance with his wishes. The records of the weight of cupola metal and blown metal are generally made in a pocket-book by the "blower," from which they are transferred to the charge sheet. It is, however, advisable to use a form for recording these details, which may be bound in book form of pocket size. The following is a copy of this Form III.

A, B, C Co., Ltd.
BESSEMER STEEL PLANT
FORM III
NUMBER OF HEATS AND WEIGHTS OF CHARGES
Shift Date

Heat No.	Weight of cupola metal to converter.	Weight of physic from cupola.	Weight of finished steel in ladle.
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			

The particulars on Forms I, II, and III are transferred to the "Heat Sheet" at the end of each shift.

2. **Other Materials used in Aid of Manufacture.**—The cost clerk keeps a list of the materials which are termed "other," to distinguish them from raw materials. These materials include the following:—

(*a*) All refractory materials used in lining and repairing the converters, cupolas, crucible furnace, ladles, etc.
(*b*) All metals used in repairs.
(*c*) All stores.

Under (*a*) are the following:—

Silica blocks of various sections, each different in price.
Silica bricks, special shapes.
Silica bricks, ordinary shapes.
Silica cement.
Fireclay blocks of various sections.
Fireclay bricks, special shapes.
Fireclay bricks, ordinary shapes.
Fireclay cement.
Fireclay.
Ganister, fine.
Ganister, rough.
Clays, specially ground.

Under (*b*) are included:—

All kinds of metals, forged and cast, used in replacing worn, broken, and defective parts of the structure and plant. Also the various tools used at the cupolas and converters.

Under (*c*) are included, among other items:—

All kinds of oils, fats, tallow, soap, waste, packing, asbestos, wipers, crucibles, gloves, leggings, brushes, files, black-lead, etc.

Issue of Materials from Store.—Any materials which are kept in stock are issued from the store on receipt of a form initialled by a responsible person. Materials to be used in aid of the steel department may be drawn from the store also by any other department of the works, but the number of the order given by the steel department superintendent must be quoted on the stores form. The forms need not be large, 3″ × 2″ being as a rule quite sufficient, and for convenience they may be in book form, so that they can be carried in the pocket of the foreman or leading hand, whose authority will be accepted by the storekeeper.

The following is a copy of the Stores Form :—

A B C Co., Ltd.
STORES

Department Order No.
Shift Date
Please supply bearer with the following :—

Materials.	No.	Size.	Weight.

Signed

These forms are sent direct from the stores to the cost clerk, and from them the total cost of stores issued in aid of steel making is prepared, and entered in the summary of costs under the heading of "Stores and Repairs." Such materials as ganister, cements, and bricks, which are kept in sheds near the steel plant, should be weighed and counted respectively before issue. This is sometimes considered unnecessary and irksome, but to ensure accurate costing it is essential. A wise superintendent or foreman will draw sufficient materials at one time to save sending frequently to the stores. There is always ample provision about a steel plant for bins for a small stock of the various materials in constant use. Where the available storage space is limited, truck or cartloads of ganister and similar materials, after their weight has been checked on the weighbridge, are frequently emptied right away into suitable bins, in close proximity to the converters and cupolas. When this practice is carried out, a list of all materials delivered over the weighbridge is sent to the cost office daily or weekly, according to the frequency of the supplies.

Whichever system is in vogue, an account of all the material used between Monday and Saturday should reach the cost clerk not later than the following Monday morning.

3. **Fuel.**—In accounting for the fuel used, such items as the following are included :—

Coke and wood used in lighting fires in cupolas, converters, and crucible furnaces, warming ladles and heating ferro-alloys (if neither gas nor oil is used for these purposes), coal or coke used on steam cranes.

Coke used in forming the bed of cupolas and in melting charges, in heating converters, in heating crucible furnace, and for other purposes.

The bulk of the fuel used is coke, which is generally supplied in railway trucks or in carts, according to the situation of the works. When received, a record of

its weight at the weighbridge is made in the raw materials ledger, and the coke is then deposited in piles or bins conveniently situated in relation to the lifts for cupola and converter stagings. From the bins the coke is taken in barrows or light railway trucks to the weighbridge at the lift, and the charge recorded on Forms I and II before being raised to the charging platform.

In addition to these records it is necessary to have a Fuel Form for miscellaneous fuels for the purposes named above, otherwise a very considerable difference may be found between the weights recorded at the weighbridge as the fuel is received and those shown on Forms I and II. A convenient form is as follows (No. IV) :—

A B C Co., Ltd.
BESSEMER STEEL PLANT
FORM IV.
MISCELLANEOUS FUELS

Shift Date

Fuel used.	Weight in cwts.		
	Converter.	Cupola.	Crucible, ladles, and heating furnaces.
Coal, slack			
,, cobbles			
Coke, hard			
,, soft			
Wood			
Oil			

To be handed to Foreman at end of shift.

From Form IV the steel superintendent enters on the Daily Heat Sheet the amount of fuel used, and the cost clerk calculates the cost accordingly.

4. **Power.**—This item of cost is more easily and accurately recorded than any other. Measuring instruments are now so numerous and exact that electrical power consumption at least, can be determined with the greatest degree of accuracy. Modern steel plants such as the type now referred to, as well as the machinery used in conjunction with the plant, are usually operated electrically. Whether the power used for operating the blowers, lifts, cranes, etc., of the steel plant is taken from a generating station in the works, or from a supply company's mains, a meter for registering the amount of current used by the steel plant should always be fixed to the sectional switchboard. From the meter it is very simple to take the readings. If a day shift only is at work, the records are made each day after work ceases. If a night shift is also employed, readings are recorded at the end of each night and day shift.

The power log sheet (Form V) is as follows, and indicates the total kilowatts consumed per shift for a week's run :—

A B C Co., Ltd.

BESSEMER STEEL PLANT

FORM V

ELECTRICITY—POWER AND LIGHTING

Week ending

Day.	Shift.	Power meter readings.		Power units consumed.	Lighting units consumed.
		At beginning of shift.	At end of shift.		
Monday	Day Night				
Tuesday	Day Night				
Wednesday	Day Night				
Thursday	Day Night				
Friday	Day Night				
Saturday	Day				
Total units consumed during week					

Automatic recorders are sometimes employed, but reliable records can be obtained if the log sheet is kept properly.

A definite price per kilowatt hour is arranged by the manager, for the electric power supplied to the steel department. If power, however, is purchased from an outside source, the price per kilowatt hour is fixed by contract. In either case, the labour of the cost clerk in determining the cost of power is a matter of multiplication only.

Some adjustments for power require to be made occasionally, as the auxiliary plant used on some parts of the steel plant is also used for other departments. The power consumed by the apparatus or cranes in question should therefore be ascertained and deducted. This calculation need only be done once, as the proportionate use of cranes, for instance, in the casting shop would not vary much as long as steel was being produced.

The current for lighting may be reckoned quite separately, as on account of the cost per unit being higher than for power, independent meters are usually fixed to record the consumption for lighting. On Form V a column is given showing the units consumed in lighting.

Form V need not necessarily be sent to the steel superintendent or foreman, but it is advisable to do so in order that he may see what consumption is being recorded against his department from week to week, and also to prevent any errors passing to the cost clerk. The former therefore reviews all the forms, except the store sheets, which go direct to the cost clerk. The steel superintendent or foreman need not, of course, see the store forms again, as he has either made them out himself, or they have been made out to his order number, by some accredited person.

Daily Heat Sheet.—Form VI (see Plate X) gives an outline of the daily heat sheet, to which reference has been made already. As the number of columns

required for the records is rather large, it is necessary to have a sheet about $18'' \times 7''$, to allow sufficient room for the items included. These forms are most convenient in book form, and should be kept by the steel superintendent. It is customary to have the books made with duplicate leaves, both bearing the same number, and each pair being numbered consecutively. The object of duplication is that the superintendent may retain in his office for reference a record of the heats produced, while the top copy goes daily to the cost clerk. The items on the sheet illustrated in Form VI are sufficiently clear without further description. All the information required by the cost clerk can be filled in by the steel superintendent before the sheet is sent to the cost office. The column for analysis of material is not dealt with until the sheet is passed from the cost clerk to the laboratory, where the chemist records the analyses and files the sheet for reference.

5. **Labour.**—In recording the amount of labour expended in the manufacture of steel, several methods are adopted, all of which aim at accuracy and simplicity. If the workmen are paid by "tonnage," the price per ton and the output in tons determine the total amount of money available for distribution. The subdivision of the money is made according to the classes of labour employed, the number of shares for each man being determined by the steel superintendent. The time office clerk, who has a list of the shares, divides the total tonnage money accordingly when preparing the wages sheet. The old method of giving the leading-hand or foreman the total "tonnage money" earned by the gang, and allowing him to divide it among the men in the proportion he cared to determine, was open to much question. It was usually the foreman himself who benefitted most by this arrangement.

In addition to the share list kept by the time clerk, records are also supplied to him of the actual number of hours each man is employed. In most works the card system of "clocking" is adopted, and is not only reliable but simple. Whether a man is employed as a piece-worker or day-worker, the clock check is best. The method still adopted in many works of getting the workmen to deposit each call, a metal ticket with his number upon it, is cumbersome and more subject to error than the automatic registering clock.

It is not intended here to describe systems of time-keeping and checking, but to illustrate how reliable data regarding cost of labour can be transferred to the cost sheet. By the means indicated, this can be done for the gangs employed on the steel plant. For the men, however, who do repairs, and then only occasionally, a form upon which definite instructions are given is sent to the foremen of the various departments from which assistance is required. The steel superintendent therefore knows all the charges made for labour against his department during the week, and if they have not been authorised, payment is not sanctioned. Form VII gives an outline of order, which is the authority for a charge being made against the steel plant by an outside department.

Form VII may be in book form, each page being perforated and easily removable when filled in. The sheet need not be larger than $3'' \times 2''$. If a plumber, electrician, or any man be sent to do the repair, the foreman of the department to whom the request has been made has only to hand the note to the man he wishes to send, and the man enters the number of hours he spends on the job on the same form, which is ultimately given to the timekeeper, who checks same and makes a charge accordingly. Each week, before the wages sheet is made up, the total time spent in each department in aid of the steel plant is handed to the steel superintendent for review and approval. The wages sheet is sent to the cost clerk, who divides the amount into two separate items:—that actually absorbed in steel making, and the wages paid for repairs. Should any query be made by the principals when reviewing the summary of

costs about the amount of expenditure on labour, the actual details of time taken on each item of repair can be seen from Forms VII issued during the week in question, and from the record of time spent by the regular repair hands employed by the steel department on daily repairs.

A B C Co., Ltd
BESSEMER STEEL PLANT
FORM VII
REPAIR ORDER

Shift Date
To Department

Please send to see to
and charge time to No.
Time taken hrs.
Signed Man's No.
Signed

When workmen are employed on an hourly rate and not by the "piece," a list of the rates of pay is kept by the timekeeper for the preparation of the wages sheet, and also by the cost clerk, simply for reference and as a means of checking. Among other items of labour included in the steel department costs is a proportionate share of the general expenses, for example—directors, managers, clerks, timekeepers, watchmen, weighbridgemen, yard labourers, etc. Such item is added as a fixed expense along with other fixed expenses of management which cannot be recorded separately.

Summary of Costs.—The cost clerk is able to prepare the weekly summary of expenditure with a minimum of labour when having in his possession a complete list of the materials and power used, labour expended and steel produced during the week, together with details of the fixed charges for depreciation and interest on plant and the proportion of the expenses of management to be charged to the steel department. Form VIII (see Plate X) illustrates the summary sheet. As the items are only entered each week on this sheet, it should be kept in a suitable folder, and passed to and from the cost office for inspection by those concerned. A suitable size for Form VIII is about $20'' \times 15''$, which allows sufficient room for the various columns.

As accuracy is absolutely essential in costing, it is important that the figures handed to the cost clerk for the assembling of costs should be beyond question. The cost clerk's duty is to piece together the information handed to him. Insistence upon the accuracy of all parties concerned is therefore imperative, otherwise the labour is in vain and the resulting costs are misleading.

The value of accurate details of cost, assembled in the columns of the summary sheet, is appreciated from week to week in detecting fluctuations in the tonnage produced and in observing the comparative differences in the items of costs each week. Losses due to bad heats, frequent renewals of tuyeres or linings, stoppages, or other causes, can be seen at a glance, as everything which goes to raise the weekly expenditure of any item is mentioned in the remarks column. These remarks, which are recorded by the superintendent in the first place against the heat in question on the daily heat sheet, are transferred to the

summary sheet by the cost clerk. Should any remarks appear irregular or insufficient to account for the rise in the expenditure, further explanations are called for by the principals. A methodical examination of the facts contained in the summary sheet will keep the principals in touch with the cost of steel production weekly, without much expenditure of valuable time. It is also a satisfaction to the steel superintendent or foreman to know that the officials are following the outputs and costs, giving an incentive to still better records. The weekly inspection has also a salutary effect upon "slackers."

The foregoing method of assembling the costs of steel made by the surface-blown converter plant is applicable to all other processes of steel manufacture, the forms being modified to suit different items of cost.

CHAPTER XLVIII

LABOUR COSTS IN STEEL MAKING

Comparison of Labour and Operating Costs.—The cost of labour per ton of steel produced by the various processes, together with the weekly outputs in tons, is given in Table CVI. The percentage of labour to the total operating costs for each output is also given, and varies from 16 per cent. for refining steel in the electric furnace, to 50 per cent. for making small outputs of steel in the open-hearth furnace. The other labour costs in Table CVI vary principally from 23 per cent. to 39 per cent. of the operating costs.

The lowest operating costs recorded are those of the large Bessemer plant, and the next lowest, of the Talbot process. The operating costs include all items, except the metal and fluxes used in the charge.

TABLE CVI

LABOUR (WAGES AND MANAGEMENT) PER TON, COMPARED WITH OUTPUT AND AS A PERCENTAGE OF OPERATING COSTS

Process.	Labour per ton of steel.			Output per week.	Operating costs, exclusive of materials.			Percentage of labour to total operating costs.
	£	s.	d.	Tons.	£	s.	d.	%
Crucible, coke-fired	1	16	9	25	5	3	7	35
„ gas-fired	1	16	9	25	3	18	3	47
Bessemer converters, small	0	5	2½	320	0	16	2	32
„ „ „	0	6	7	160	0	19	0	35
„ „ „	0	7	6	84	1	0	7½	36
„ „ „	0	9	0	30	1	8	9½	31
„ „ „	0	12	0	18	1	11	8	38
„ „ large	0	2	6	3780	0	8	10½	28
Open-hearth furnace, small	0	18	0	25	1	16	4	50
„ „ „ medium	0	7	2	255	1	2	1	32
„ „ „ large	0	5	3	5000	0	13	11	38
Talbot furnace	0	4	6	1200	0	11	5	39
Héroult electric furnace, refining	0	1	1½	1000	0	6	10½	16
„ „ „ cold charge	0	9	0	50	1	19	5	23

During recent years, the amount of labour required to operate steel plants of large capacity has been very greatly reduced by the introduction of mechanical charging machines, and other automatic handling devices for raw materials and fuels used at the furnaces. For instance, the charging by hand of a 25-ton open-hearth furnace where 70 to 80 per cent. of scrap is used, takes from 7 to 8 hours, whereas a furnace of 100 tons capacity, charged with equal amounts of liquid iron and cold steel scrap, can be charged in from 1 to 2 hours.

Wages of Steel Workers.—Comparing the wages of steel workers in different countries it is found that Germany pays about 20 per cent. less than England, and from 40 to 50 per cent. less than America. The following table gives an

approximate comparison of the wages paid to men employed at open-hearth furnaces in the three countries :—

TABLE CVII

WAGES PAID TO OPEN-HEARTH FURNACE MEN IN THE UNITED KINGDOM, THE UNITED STATES, AND GERMANY

Kind of labour.	United Kingdom. Per shift of 12 hours.	United States. Per shift of 12 hours.	Germany.[1] Per shift of 12 hours.
Head melter	12/- to 14/-	20/- to 24/-	10/- to 14/-
First helper	9/- to 11/-	11/- to 12/6	9/- to 11/-
Second helper	5/6 to 6/6	7/- to 8/-	5/- to 6/-
Crane men	5/6 to 7/-	12/- to 13/-	4/6 to 5/-
Charging-machine hand	5/- to 6/6	9/- to 10/-	4/- to 5/-
Casting-pit men	5/- to 6/-	7/- to 8/-	4/8 to 5/8
Steel pourers	6/- to 8/-	12/- to 13/-	—
Labourers handling slag and scrap	4/6 to 5/6	6/- to 7/-	4/3 to 5/-
Common labourers	4/- to 5/-	5/- to 6/-	4/- to 4/6

[1] "Bulletin of the American Association of Commerce and Trade," Berlin, 1912.

The description in Table CVII of the kinds of labour, differs in the three countries. For instance, in the United Kingdom, leading men on the charging platform are usually called 1st, 2nd, and 3rd melters ; the first being in charge. In America, the same men are generally called the melter, 1st hand and 2nd hand, while in Germany, the head melter is called the foreman, the 2nd melter assistant foreman, and the others, 1st, 2nd, and 3rd melters.

Fluctuation of Wages.—No fixed universal standard of wages is adopted. Wages vary, not only in different countries, but in various parts of the same country. The laws that govern them are very complex, being influenced by several conditions, such as, "standard of living," "supply and demand," "markets," etc. Different systems of payment are adopted, but the worker is usually engaged on "time" or at so much per hour, or "piece," or so much per output. Elaborate schemes are in vogue for systematising wages and stimulating the worker, but no finality has been reached in producing contentment.

Mr. Sanders, President of the Ingersoll-Rand Co., New York, made investigations in different countries during the latter end of 1911, regarding wages paid for labour. He states,[2] that while the price of mechanical labour in the United States has stood comparatively still, or has made but a moderate advance during the past 20 years, the price of similar labour in Germany and England has increased at least 100 per cent. Mechanical labour in Germany, which is to-day one-half that of the United States, was one quarter 20 years ago. The value of German labour is steadily increasing, and at a more rapid rate than the price of labour in England and America.

With reference to the fluctuation of wages in England, Mr. George H. Wood,[3] showed how the Sheffield and district wages had fluctuated from 1840 to 1906, in the iron, coal, and engineering trades. Taking the wages value in 1883 at 100 for the four classes of labour given in Table CVIII, the fluctuations are indicated by the rise and fall in the numbers for different years.

[2] "Iron Age," 1912, Feb. 29, p. 522.
[3] Report of British Association, 1910, pp. 690 and 691.

TABLE CVIII

FLUCTUATION IN SHEFFIELD AND DISTRICT WAGES FROM 1840–1906

Year.	Puddlers.	Coal hewers.	Building.	Engineering.
1840	87	67	—	—
1855	125	86	86	73
1860	100	82	83	73
1874	145	134	101	94
1877	103	96	108	97
1883	100	100	100	100
1886	96	91	101	100
1891	100	127	105	101
1900	128	133	116	107
1906	113	118	116	108

In 1855, the wages for puddlers were higher than in 1906, while in the engineering trades, the wages have steadily increased from 73 in 1855 to 108 in 1906.

Wages and Cost of Living.—From investigations[1] made as to the cost of labour and living in Germany, and from similar investigations made in England by the Board of Trade, the following interesting figures are given :—

TABLE CIX

WAGES PAID IN ENGLAND AND WALES AND GERMANY.

Trade.	Predominant range of weekly wages in October, 1905, in				Ratio of mean predominant wage in Germany to mean predominant wage in England, taken as 100.
	England and Wales.	Germany.			
Engineering—	Average.	Average.	Highest at Essen.	Lowest at Chemnitz.	
Fitters . . .	32/- to 36/-	26/- to 32/-	30/- to 39/-	21/- to 24/-	85
Turners . . .	32/- to 36/-	27/- to 33/-	32/6 to 39/-	24/- to 26/-	88
Smiths . . .	32/- to 36/-	28/6 to 33/-	30/- to 36/-	25/- to 27/-	90
Pattern makers .	34/- to 38/-	25/6 to 30/-	27/-	25/- to 27/-	77
Labourers . .	18/- to 22/-	18/- to 22/-	20/- to 23/-	14/- to 17/-	100

At the same period, the average number of hours per week in England was 53 against $59\frac{1}{2}$ in Germany, or 12 per cent. higher in the latter.

Comparing the commodities used by the same classes of people in both countries, Table CX shows that the prices paid in Germany are, in most cases, 20 to 40 per cent. higher than those paid in England, with the exception of those for milk and potatoes, which are lower in Germany.

[1] "Iron and Coal Trades Review," 1908, p. 381.

TABLE CX

COST OF COMMODITIES IN ENGLAND AND GERMANY

Commodity.	Predominant Prices in October, 1905, in		Ratio of mean predominant prices in Germany to mean predominant prices in England, taken as 100.
	England and Wales.	Germany.	
Sugar, white, granulated, per lb.	$2d.$	$2\frac{1}{4}d.$ to $2\frac{1}{2}d.$	119
Butter, per lb.	$1/1\frac{1}{4}$ [1]	$1/-$ to $1/2\frac{3}{4}$	105
Potatoes, per 7 lbs.	$2\frac{1}{2}d.$ to $3\frac{1}{2}d.$	$2\frac{1}{4}d.$ to $3d.$	88
Flour, wheaten, per 7 lbs.	$8d.$ to $10d.$	$11\frac{1}{2}d.$ to $1/1\frac{3}{4}$	140
Milk, per quart	$3d.$ to $4d.$	$2\frac{1}{2}d.$ to $2\frac{3}{4}d.$	75
Beef, per lb.	$7\frac{1}{2}d.$ to $8\frac{1}{2}d.$ [2] $5d.$ to $6d.$ [3]	$7\frac{3}{4}d.$ to $8\frac{3}{4}d.$	122
Mutton, per lb.	$7\frac{1}{2}d.$ to $9d.$ [2] $4d.$ to $5d.$ [3]	$7\frac{3}{4}d.$ to $9\frac{3}{4}d.$	137
Pork, per lb.	$7\frac{1}{2}d.$ to $8\frac{1}{2}d.$	$8\frac{3}{4}d.$ to $11d.$	123
Bacon, per lb.	$7d.$ to $9d.$	$8\frac{3}{4}d.$ to $11d.$	123
Coal, per cwt.	$9\frac{1}{2}d.$ to $1/-$	$10\frac{3}{4}d.$ to $1/4$	124
Paraffin oil, per gallon	$7d.$ to $8d.$	$9\frac{1}{4}d.$ to $11d.$	135

[1] Colonial, or foreign and Danish. [2] British or Home-killed.
[3] Foreign or Colonial.

The rents of workmen's dwellings in Germany are about the same as in England, namely two rooms, *3s.* to *3s. 6d.* per week, *3s. 6d.* to *4s. 9d.* for three rooms, and *4s. 3d.* to *6s.* for four rooms.

Taking the various items into consideration, it is estimated that in the German engineering and shipbuilding trades, the wages paid per hour amount to about 75 per cent. of the English rate, and the cost of rent, food, and fuel, is nearly 20 per cent. greater.

The United States and Canada.—From personal investigation in several of the steel manufacturing centres in the United States and Canada during 1912, we found the following rates of labour and living. Table CXI gives the rates of pay per day in the States and Canada, where a 10-hour day is in vogue for most workers, except in steel departments where the shifts are almost entirely of 12 hours' duration.

With reference to the cost of living, the following commodities cost about the same in the U.S.A. and Canada as in England—tea, eggs, butter, milk, flour, potatoes, beef, mutton, bacon, boots, and coal; clothing is approximately $1\frac{1}{2}$ times dearer. Rent is from $1\frac{1}{2}$ times to twice the amount paid in this country, for corresponding comforts. An unmarried working man can board and lodge comfortably in the States or in Canada on from *15s.* to *20s.* per week. Generally, the cost of living in the U.S.A. and Canada on the same scale that the workers live in England is about 50 per cent. higher.

TABLE CXI

WAGES IN THE U.S.A. AND CANADA

Kind of labour.	U.S.A.	Canada.
Engineering—	Per day.	Per day.
Fitters (mechanics)	12/- to 13/-	12/- to 13/-
Turners	12/- to 13/-	12/- to 13/-
Machinists	7/- to 18/-	12/6 to 14/-
,, automatic (youths)	6/- to 8/-	—
Machine plate workers	13/- to 20/-	—
Labourers, common	4/3 to 8/-	4/3 to 8/-
Steel and iron works—		
Blast furnace charge hand	11/6 to 12/6	—
,, ,, second hand	10/- to 11/-	—
Labourers	6/- to 7/6	—
Open-hearth furnace—		
Melter	20/- to 24/-	20/- to 24/-
First hand	11/6 to 12/6	11/6 to 12/6
Second hand	7/- to 8/-	8/- to 9/-
Labourers	5/- to 6/-	5/- to 6/-
Cranemen	12/6	12/6
Chargemen	10/-	10/-
Bessemer converters—		
Charge hand	14/- to 16/-	—
Converter men	10/- to 12/-	—
Labourers	6/- to 7/6	—
Electric furnace steel making—		
First hand	22/-	—
Second hand	14/-	—
Third hand	8/6	—
Draughtsmen	50/- to 100/- (per week)	50/- to 100/- (per week)
Pattern makers	12/- to 15/-	12/- to 15/-
Moulders	10/6 to 14/-	10/6 to 14/6
Core-makers	10/6 to 14/-	8/6 to 11/6
Grinders	8/6 to 10/6	8/6 to 10/6
Finishers	10/6 to 12/6	10/6 to 12/6
Buffers and polishers	—	10/- to 11/-
Iron machinists	9/- to 12/6	10/6 to 12/6
Tool makers	12/- to 15/-	10/6 to 12/6
Blacksmiths, light	11/6 to 12/6	11/6 to 12/6
,, heavy	14/- to 19/-	14/- to 18/-

The usual hours for work in the Canadian factories are from 7 a.m. to 6 p.m.

The United Kingdom, the U.S.A., and Germany.—From the foregoing facts, it is evident that the German worker is paid less for his labour, and has to pay more for his living, than the British workers. There are exceptions. The common labourer, for example, in steelworks, is paid about the same in Germany as in England, and only a little less than in the United States. The spending power, therefore, of the British and German worker's wage is equal, if not slightly better than the American's. On the other hand the higher-paid steel workers, such as the leading melters on open-hearth furnace plants, when living on a corresponding scale, are more favourably placed than their fellow-workers of Germany and the United Kingdom.

The efforts which are being constantly made to adjust the earnings of the workers to make the standard of living and wage-earning capacity comparable, will be more readily accomplished by a systematic classification and valuation of labour

Classification of Labour.—In all branches of labour, the necessity for rightly valuing and standardising each kind of labour has been recognised and put into practice for many years. In addition to the two main divisions, "skilled" and "unskilled," many subdivisions of labour naturally suggest themselves, according to the trade under consideration. In some trades, the work of classifying is more difficult than in others, but in every case it proves beneficial to employer and employed. The Trade Unions have made their own classification, and in some cases have controlled the wage value of each class of labour.

In the Government factories of Britain and America, and in Krupp's works in Germany, as well as in large works in our own country, such as the Hadfield Steel Foundry Co., Ltd., Sheffield, standardisation of labour has been effected with beneficial results. For instance, during recent years in our own Government factories, the classification and value of labour has been thoroughly standardised under the direction of the chief superintendent, Sir H. F. Donaldson, K.C.B., the result being that while better wages are paid, more work is done, with a greater degree of efficiency and at less cost.

What has been accomplished in determining the true value of each kind of labour in the various branches of the Ordnance Factories, is now being carried out by the United States Government in their investigations into the conditions of labour in the steel industry of the United States. Sidney G. Koon [1] gives an interesting account of one set of investigations made in a large steelworks at Pittsburg, from which the particulars of labour on open-hearth furnaces are given.

Labour on Open-hearth Furnaces.—This is classified as "hard," "medium," "light," and "observation," and under these headings is given the actual number of hours each man was employed during the period under consideration. The movements of nine men operating the open-hearth furnace were studied, and the times recorded by stop-watches give the actual time each man was working and idle.

TABLE CXII

WORKING AND IDLE TIME AT OPEN-HEARTH FURNACE

Men.	Observed time.				Percentages.	
	Work.		Idle.		Work.	Idle.
	Hours.	Mins.	Hours.	Mins.		
Charging machine operator	20	24	27	36	42·5	57·5
1st helper	8	58	24	02	27·2	72·8
2nd ,,	22	04	25	56	46	54
3rd ,,	17	46	30	14	37	63
Ladle craneman	24	46	23	14	51·6	48·4
Steel pourer	14	24	33	36	30	70
Brakeman and Engineer [2]	15	54	16	06	49·6	50·4
Stripper craneman	11	03	18	57	36·7	63·3
Mean hours	16	48	23	59	41·2	58·8

Mr. Koon, in referring to the high percentage of idle time of the steelworker compared with that of those engaged in other classes of labour, mentions

[1] "Iron Age," Feb. 1, 1912, p. 312.

[2] The locomotive engineer and brakeman are grouped as one unit, with a total of 32 hours absorbed.

the long hours of the open-hearth furnace worker, and the intense heat to which he is subjected. Nearly every steelworks runs a 12-hour shift, and open-hearth furnace men when "fettling" the furnace bottom between the charges, are exposed to an almost unbearable heat. The observations recorded in Tables CXII and CXIII were made during the first 10 days of Aug., 1911, and out of the 48 hours noted, the actual time taken by the 1st, 2nd, and 3rd helpers in fettling the furnace bottom was 9 hours 34 minutes, or 19·6 per cent. The 1st helper was watched for 33 hours, the stripper craneman for 30, while the charging machine operator, the 2nd and 3rd helpers, ladle craneman, and steel pourer were watched for 48 consecutive hours. The following subdivision of labour was made in percentages of the total working time:—

TABLE CXIII

INTENSITY OF WORK

	Hard.	Medium.	Light.	Observation.
1st helper	32·7	27·4	11	28·9
2nd ,,	72·8	19·6	7·6	—
3rd ,,	67·9	13·5	18·6	—
Mean. for the 9 men in Table CXII	30·0	6·1	62·2	1·7

The terms "hard," "medium," "light," and "observation," as given in the investigation, no doubt served the object the investigators had in view, but they are somewhat vague when generally used for classifying labour in steelworks without some qualification. For instance, the craneman's duties are referred to as being "light," which term may be all right when compared only with the physical labour in fettling the bottom of an open-hearth furnace, but one can easily conceive of his duties being "hard" in the sense of mental strain or exhaustion, if operating a difficult crane in a shop where clouds of fumes ascend and hang around the crane cage.

Then again, work is "light" or "hard," according to the rate of output and the ability of the worker. In some steelworks we have witnessed the same operations performed by hand at twice the rate as in other steelworks. The human element accounts for the difference, and is always a determining factor, whatever the classification or valuation of labour, and therefore influences the wages of the worker who is employed on piece-work.

Hours of Labour for Steel Workers.—Most of the steel workers on continuous operating furnaces are employed for 12 hours per shift. This is a common practice in Britain, America, and Germany. In America the plants are usually kept going constantly until repairs are necessary, the hours being, for the day-shift, from 7 a.m. to 5 p.m. during 6 days of the week (making 60 hours), and for the night-shift commencing Sunday morning at 7 a.m., and working 24 hours, and for the remaining 6 days from 5 p.m. to 7 a.m, making 108 hours. The men work alternately night and day shifts.

For some time a vigorous movement has been carried on against the seventh day's labour and the 12-hour day. Mr. Chas. M. Cabot, of Boston, has been influential in bringing about reforms. Other workers have proved that an 8-hour shift can be successfully run on open-hearth plants. Mr. R. A. Bull[1]

[1] American Foundrymen's Association, Buffalo Convention, Sept., 1912.

states that at the Commonwealth Steel Co.'s open hearth plant, the 12-hour shift has been abandoned, and the 8-hour shift substituted. The shift hours under the old plan were 6 a.m. to 6 p.m., and 6 p.m. to 6 a.m.; under the new, 7 a.m. to 3 p.m., 3 p.m. to 11 p.m., and 11 p.m. to 7 a.m. The gangs change on the first day of each week. From the results recorded, a saving was effected by the change, although the hourly wages of the workers were increased by from 14 to 22 per cent. Cases are on record where men, released from the seventh day's labour, have sought and obtained employment elsewhere on the idle days, appearing on the pay-sheet of another firm under another name.

We believe that by the general abandonment of steel manufacture on Sundays, and the employment only of labour necessary for furnace plant attention, the worker would give more efficient service without any loss to the employer.

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